Smart Solutions, Practical Results

Independent Electric Distribution Reliability Study for Columbia, MO

PREPARED FOR: Columbia Water & Light Department (CWLD)

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VERSION HISTORY:

Version	Date	Description
Draft	4/3/2018	Current Distribution System Assessment
1	4/11/2018	City comments and substation transformers rating methodologies added
2	7/5/2018	Includes the City comments
3	8/24/2018	Final Report
4	1/15/2018	Signed final report

EXECUTIVE SUMMARY

Columbia Water & Light Department ("CWLD") has eight substations located throughout its service territory. Sixty (60) distribution circuits (including stand-by, dedicated, and normal circuits) feed the CWLD's service territory at the 13.8 kV level. CWLD has been evaluating the load serving capability of its electric system, especially to address potential development in the south western part of Columbia, MO ("the city"). Over the past few years, CWLD has evaluated several options meeting forecasted load growth, including a project that would add transmission lines to establish a new Mill Creek substation on Peach Tree Drive. This report presents the results of an independent third party study exploring the adequacy of existing substation and distribution feeder capacity to meet anticipated future loads. The scope of this study does not include any evaluation of 69kV or 161kV facilities.

The study results show the distribution circuits are capable of handling the existing CWLD system load up to and including forecast load growth of 5.62% of the current peak demand. No voltage or thermal loading violations were calculated for loads up to 105.62% of 2018 forecast loads, with the exception of Circuit PC 221. Low voltages on PC 221 would require the installation of a voltage regulation device in the short term to correct risk of low voltage.

The results of the substation capacity adequacy assessment indicate that the existing substation capacity should be adequate for five years. This assessment is based on the assumptions that all of the substations would experience up to 5% annual compound, non-coincident load growth, and that feeder to feeder load transfers could be performed in a timely manner to avoid N-1 transformer loading above nameplate ratings.

The distribution system study created power flow models of all distribution circuits based on GIS graphical and equipment data provided by CWLD. Feeder loading was modeled based on non-coincident feeder peak demand. Feeder egress thermal loading was determined based on CWLD underground system construction standards, ambient temperature assumptions, and cable type and cross-section. The study also assessed the distribution circuit voltage and thermal loading performance for 2018 peak system conditions. Feeder load growth was estimated based on aggregate system load forecast data. The growth rate was applied to the circuit power flow model to assess future voltage and thermal loading performance. The steady state studies were performed using CymeDist tool.

The ampacity study results, which calculate the feeder egress capacity, indicate that the feeder loading could be increased by about 1 MVA from currently assumed values. Emergency thermal feeder ratings were calculated based on short term high temperature operation. The use of such ratings, based on a risk tolerance assessment, could add another 1 MVA of load carrying capacity to address short term emergency conditions.

Substation transformer capacity adequacy was evaluated based on present and forecast substation load, substation N-1 transformer capacity, and feeder to feeder load transfers. Load transfers to adjacent substations were limited by feeder thermal ratings using existing CWLD circuit capacity standards, voltage limits, and transformer nameplate capacity. Normally open bus tie breakers were not closed to increase the transformer load carrying capability in adjacent substations. Compound annual substation load growth of 2-5% over five and ten years was considered to evaluate future substation transformer capacity adequacy.

A sustained non-coincident compound load growth at all substations has been used as a planning tool to identify substations which may have future capacity adequacy issues. Using a 3% annual load growth assumption, the ten year out results indicate that the Perche Creek, Harmony Branch, and Hinkson Creek substations are potential candidates to require some form of transformer capacity additions to provide loading relief should the assumed compound load growth occur. These three stations would, based on the forecast compound load growth assumed, need to utilize a loss of life rating based on transformer insulation degradation to avoid curtailing loads for in the event of a transformer outage.

Both the five year and ten year assessments should be refined at such time as improved substation load forecasts are available. In addition, the planned feeder improvements associated with Harmony T3 should be included in future evaluations.

The primary risk in assessing the substation capacity adequacy is associated with the ability to transfer loads between adjacent substations in a timely manner. This risk is mitigated by the limited likelihood of a transformer failure occurring at or near peak conditions and the thermal time constant of the affected transformers. Loads below peak values and the time delay before the affected transformers reach their maximum allowed top oil temperature will provide a buffer to allow for the implementation of pre-defined feeder to feeder switching solutions.

The primary use of a substation capacity adequacy assessment which utilizes feeder to feeder transfers and loss of life ratings (as acceptable) is to provide a means of identifying the need for substation capacity additions and provide a mechanism to defer these capacity additions subject to risk tolerance. The results of this analysis indicate that additional substation capacity may be required in future plans to relieve potential Perche Creek, Harmony Branch, and Hinkson Creek Substations. The timing and method for providing this additional substation capacity will be dependent on local development, actual load growth, and the City's risk tolerance to rely on feeder to feeder load transfers and the possible exposure to some transformer loss of life. The details of such a capacity addition plan will develop in conjunction with a detailed substation/feeder load forecast

Potential Projects to Increase Reliability

- Monitor transformer capacity adequacy at the Perche Creek, Harmony Branch and Hinkson Creek Substations based on individual substation load growth
- Include a Bus Tie for the Harmony Branch 3 Transformer and Switchgear
- Add Voltage regulation to the PC 221 feeder.

Additional Recommended Actions to gather more information

- Perform a spatial load forecast study at substation level that attempts to identify areas of the city where load growth is likely to occur
- Perform a loss of life study on the substation transformers in order to better understand acceptable overload conditions

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1 INTRODUCTION

The Columbia Water & Light Department ("CWLD") has eight substations located throughout its service territory and sixty (60) distribution circuits (including stand-by, dedicated, and normal circuits) feed the CWLD's service territory at the 13.8 kV level. CWLD has been evaluating different options to address new development and increased loads. In particular there has been system expansion forecast in the south western part of the city.

CWLD has indicated an interest in having an independent third party perform a study within the CWLD service territory exploring alternatives to compare with existing options which the city has developed. This study presents a distribution system and substation transformation system assessment. This study does not consider any enhancements to the 69kV and 161kV system.

The remainder of this report is structured as follows:

- Section 2, Distribution System Assessment, describes study methodology and results of system modeling including network, equipment, and load modeling. It also presents the study methodology and the results of the feeder ampacity study, which assesses the thermal loading capacity of distribution circuit egress.
- Section 3, Distribution Performance, analyzes the substation transformer's rating capacity under different system operating conditions. On the distribution circuit level, this section shows thermal and system voltage performance.
- Section 4, Distribution System Performance – 5 Years, describes the study results of distribution system applying load growth.
- Section 5, System Improvements, provides an overview of mitigation required to maintain the distribution system performance; it also describes substation capacity assessment under different load growth values studied as sensitivity analysis.
- Appendices provide additional information used during the present study process.

2 DISTRIBUTION SYSTEM ASSESSMENT

2.1 Distribution System Modeling

The information provided by CWLD for modeling purposes was represented in a geographic information system (GIS) graphical interface containing the topology of the circuits. CWLD also provided supplementary graphical information in the form of shape files that could be visualized in a CYME environment. CYME is an industry standard software package used by a large number of power utilities for a wide range of distribution system analyses across North-America. A CYME model was built using software version 7.2, Revision 9. Substation configuration single-line diagrams were also provided and are included in Appendix A.

The CWLD electric service territory is fed by 60 distribution circuits at 13.8 kV nominal voltage. Two circuits are for standby use. The circuits are connected to twenty transformers distributed in eight HV/MV substations, providing a total transformation capacity of 459.2 MVA. Table 1 summarizes the capacity of the eight substations of the CWLD area. These transformers feed the 13.8-kV distribution circuits.

Table 1. Substation and Transformation Capacity

Substation		Transformer	
Name	ID	ID	FOA Capacity (MVA)
Bolstad	BD	BD T1	22.40
		BD T2	22.40
Blue Ridge	BR	BR T1	22.40
		BR T2	22.40
Grindstone	GD	GD T1	22.40
		GD T2	22.40
		GD T3	22.40
Harmony	HB	HB T1	22.40
		HB T2	22.40
		HB T3	22.40
Hinkson Creek	HC	HC T1	22.40
		HC T2	22.40
		HC T3	22.40
Perch Creek	PC	PC T1	22.40
		PC T2	22.40
Power Plant	PL	PL T1	22.40
		PL T2	22.40
		PL T3	22.40
Rebel Hill	RH	RH T1	28.00
		RH T2	28.00

1

Every circuit was represented by a 13.8-kV source node. All circuits were modeled with a voltage set point between 1.00 pu and 1.03 pu. A detailed cable and conductor CYME model was built for every circuit based on the provided information. Figure 1 depicts the CWLD Distribution System modeled in CYME.

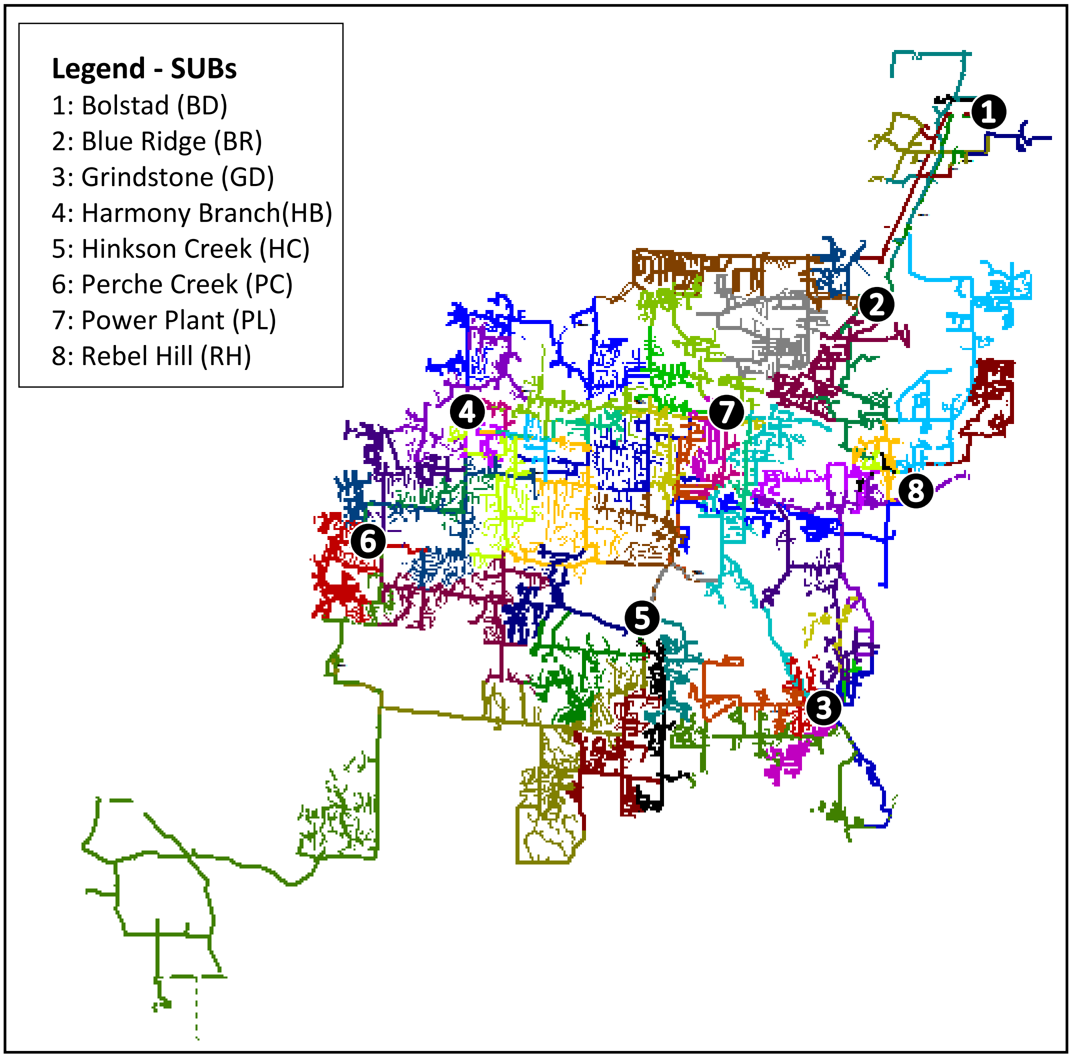


Figure 1. City of Columbia distribution system model.

Size and phasing of distribution transformers were provided by CWLD. Electrical parameters of distribution transformers were assigned typical values as described in Table 2 below.

Table 2. Typical Distribution Service Transformers Parameters

HV [kV]	LV [kV]	Power [kVA]	Phases	Z [%]	N.L. Loss [W]	X/R
13.8/7.967	0.240/0.120	5	1	3.24	50	1.54
13.8/7.967	0.240/0.120	10	1	3.24	70	1.54
13.8/7.967	0.240/0.120	15	1	3.24	80	1.54
13.8/7.967	0.240/0.120	25	1	3.24	120	1.54
13.8/7.967	0.240/0.120	37.5	1	3.15	170	1.56
13.8/7.967	0.240/0.120	50	1	3.04	190	1.60
13.8/7.967	0.240/0.120	75	1	2.94	200	1.67
13.8/7.967	0.240/0.120	100	1	2.89	250	1.72
13.8/7.967	0.208/0.120	112.5	3	2.88	270	1.75
13.8/7.967	0.208/0.120	150	3	2.87	300	1.82
13.8/7.967	0.240/0.120	167	1	2.87	330	1.85
13.8/7.967	0.208/0.120	225	3	2.89	400	1.94
13.8/7.967	0.208/0.120	300	3	2.95	430	2.07
13.8/7.967	0.208/0.120	500	3	3.06	460	2.22
13.8/7.967	0.208/0.120	750	3	5.75	500	2.22
13.8/7.967	0.480/0.277	75	3	2.94	200	1.67
13.8/7.967	0.480/0.277	300	3	2.95	430	2.07
13.8/7.967	0.480/0.277	500	3	5.75	460	2.22
13.8/7.967	0.480/0.277	750	3	5.75	500	2.22
13.8/7.967	0.480/0.277	1000	3	5.75	600	2.22
13.8/7.967	0.480/0.277	2000	3	5.75	800	2.22
13.8/7.967	0.480/0.277	2500	3	5.75	1200	2.22

136 switches were modeled as tie switches and in-line switches. The location of these tie switches is marked with green circles in Figure 2. The majority are located around the city's downtown area.

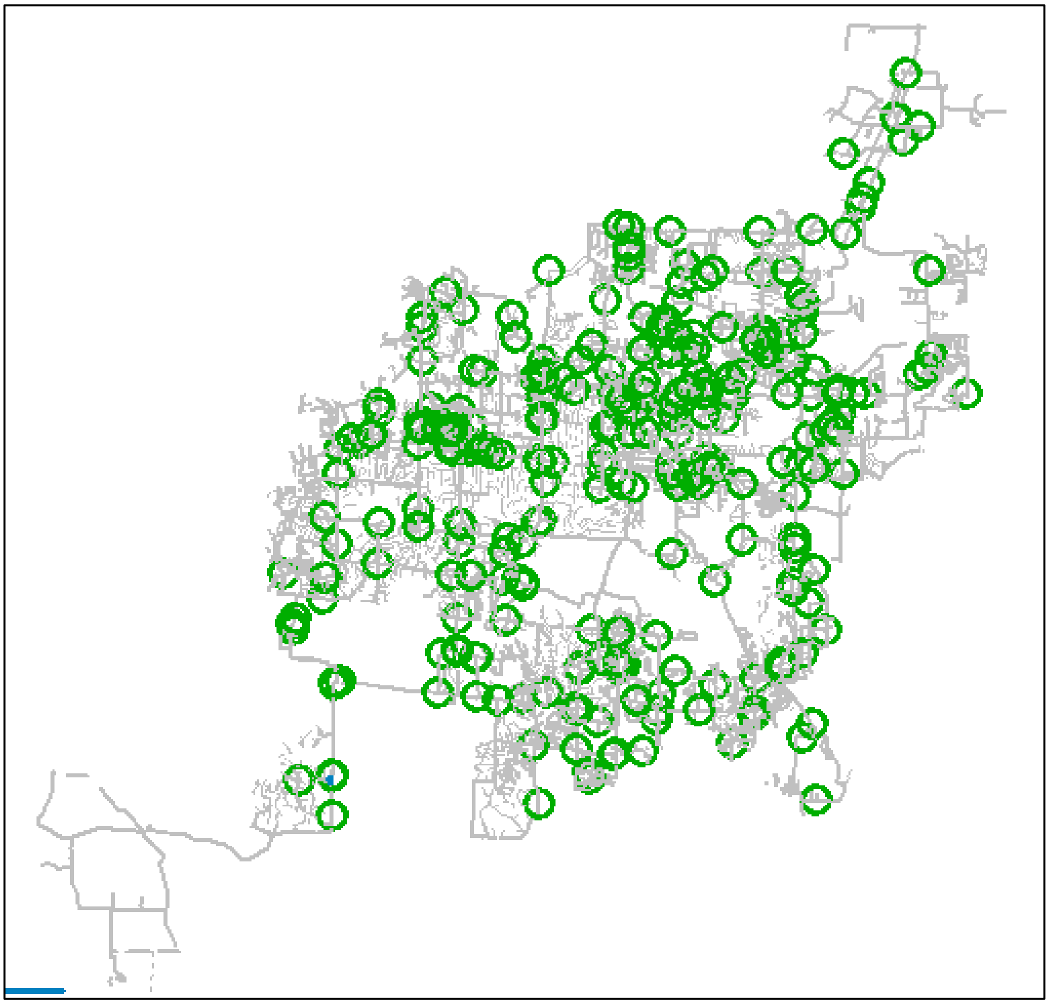


Figure 2. In-line and tie switch locations.

A total of 119 capacitor banks with a total capacity of 123.6 MVAR have been modeled in the CWLD distribution system and are distributed as follows: 9.3 MVAR on Bolstad circuits, 8.1 MVAR on Blue Ridge circuits, 8.85 MVAR on Grindstone circuits, 24.3 MVAR on Harmony Branch circuits, 21.9 MVAR on Hinkson Creek circuits, 13.5 MVAR on Perche Creek circuits, 19.5 MVAR on Power Plant, and 18.15 MVAR on Rebel Hill circuits.

279.33 miles of overhead lines were modeled as following: 11.96 miles on Bolstad circuits, 30.15 miles on Blue Ridge circuits, 21.84 miles on Grindstone circuits, 58.76 miles on Harmony Branch circuits, 38.95 miles on Hinkson Creek circuits, 43.07 miles on Perche Creek circuits, 49.83 miles on Power Plant, and 24.77 miles on Rebel Hill circuits.

492.35 miles of underground cables were also modeled as part of the CWLD's distribution system as following: 9.07 miles on Bolstad circuits, 38.43 miles on Blue Ridge, 76.39 miles on Grindstone circuits, 47.56 miles on Harmony Branch circuits, 106.65 miles on Hinkson Creek circuits, 125.71 miles on Perche Creek circuits, 32.58 miles on Power Plant, and 55.96 miles on Rebel Hill circuits. The cable capacity (Amps) for different cables implemented in the model is summarized in Table 3 below.

Table 3. Typical 13.8-kV Circuit Classification Used in the CYME Model

Cable Size	Circuit Classification (Amps)
500 CU (UG)	600 Amps class
477 ACSR (OH)	600 Amps class
4/0 AL	200 Amps class
1/0 ACSR (OH)	200 Amps class

Based on the sub-transmission one-line diagram and the medium voltage bus voltage information, the voltage set-points for different feeders were set from 1.0 pu to 1.03 pu (13.9 kV and 14.2 kV). Table 4 summarizes voltage set point at each distribution medium voltage bus.

Table 4. Distribution Circuit Voltage Set Point

Feeder/	Bus Voltage (kV)	
Circuit	Nominal	Dispatched
BD 211	13.8	14.2
BD 212	13.8	14.2
BD 213	13.8	14.2
BD 221	13.8	14.0
BD 222	13.8	14.0
BD 223	13.8	14.0
BR 211	13.8	13.9
BR 212	13.8	13.9
BR 213	13.8	13.9
BR 221	13.8	14.1
BR 222	13.8	14.1
GD211	13.8	14.0
GD212	13.8	14.0
GD213	13.8	14.0
GD221	13.8	14.3
GD222	13.8	14.3
GD223	13.8	14.3
GD231	13.8	14.1
GD232	13.8	14.1
GD233	13.8	14.1
HB 211	13.8	14.0

Feeder/ Circuit	Bus Voltage (kV)	
	Nominal	Dispatched
HB 212	13.8	14.0
HB 213	13.8	14.0
HB 221	13.8	14.0
HB 222	13.8	14.0
HB 223	13.8	14.0
HB 231	13.8	14.0
HB 232	13.8	14.0
HB 233	13.8	14.0
HC 211	13.8	13.9
HC 212	13.8	13.9
HC 213	13.8	13.9
HC 221	13.8	14.1
HC 223	13.8	14.1
HC 231	13.8	13.9
HC 232	13.8	13.9
HC 233	13.8	13.9
PC 211	13.8	14.0
PC 212	13.8	14.0
PC 213	13.8	14.0
PC 221	13.8	13.9
PC 222	13.8	13.9
PC 223	13.8	13.9
PL 212	13.8	14.1
PL 213	13.8	14.1
PL 214	13.8	14.1
PL 221	13.8	14.1
PL 222	13.8	14.1
PL 223	13.8	14.1
PL 231	13.8	14.1
PL 232	13.8	14.1
PL 233	13.8	14.1
RH 211	13.8	14.0
RH 212	13.8	14.0
RH 213	13.8	14.0
RH 214	13.8	14.0
RH 221	13.8	14.0
RH 222	13.8	14.0
RH 223	13.8	14.0
RH 224	13.8	14.0

After modeling the circuit layout (network) and equipment (switches and service transformer), circuit loading was analyzed, which includes primary services (spot loads) and circuit peak demand. The spot loads are those industrial or commercial services that draw high demand. Location and peak demand of primary service customers were provided by the CWLD (see in Table 5). The circuit peak demand and load allocation is presented in Section Load Modeling in Cyme Power Flow Model.2.3.4.

Table 5. Primary Service Loading Information

Feeder/circuit	P (kW)	Q (kVAR)
BD 212	3520	1099.1
BD 213	640.86	200.1
BD 223	294	91.8
GS 221	2998.09	936.2
HC 232	3926.61	1226.1
PC 221	1589	496
PP 212	539.61	168.5
RH 221	1948.51	608.4

2.2 Substation and Circuit Loading Analysis

The CWLD provided load profiles of each distribution circuit from 2017. From load profiles non-coincidental peak demand, utilization factor and load factor were obtained for substations, substation power transformers, and distribution circuits.

2.2.1 Substation Load and Capacity Analysis

The CWLD has a total of seven 69/13.8kVsubstations and one 161/13.8kV substation with either two or three distribution transformers per substation. These substations employ a variety of bus configurations including:

- A seven element straight bus with no bus tie breakers; e.g. Grindstone
- Four element straight bus with a bus tie breaker; e.g. Bolstad or Rebel Hill
- Seven element straight bus with a bus tie breaker; e.g. Power Plant
- Four to six element ring buses; e.g. Blue Ridge, Harmony, and Hinkson

These different configurations provide differing levels of reliability for single contingency, such as a transformer or 69kV line outage, or common mode contingency events, such as bus outages or internal faults of bus tie breakers. Straight bus configurations are typically considered to provide a lower level of reliability and flexibility than ring buses. However, the occurrence of internal breaker failures and bus faults tend to be low enough such that converting a straight bus station to a ring bus would need to be justified based on other considerations.

The CWLD utilizes a straight bus configuration with normally open bus tie breakers between bus sections supplied by a single transformer for their 13.8kV bus design. This allows the load served by a faulted transformer to be picked up by adjacent transformers in the substation by closing the bus tie breaker.

The one exception to this is the Harmony substation in that there is no bus tie between the 13.8kV bus served by transformer #3 and the buses served by transformers #1 and #2. The feeders supplied by transformer #3 would need to be remotely tied to other feeders in order to pick up the load served from a failed transformer #3.

The variety of substation configurations on the CWLD system all provide the ability to serve the individual substation loads with all transformers in service as well as for the loss of one of the transformers in a substation. The one exception, as noted, is the Harmony substation. As such a simple method of determining the rated capacity of a substation is by the sum of the rated capacity of the smallest transformers in the station under N-1 conditions. In this section, we analyzed the substation transformation capacity under N-1 contingency conditions. Section 3.1 discusses alternative methods by which the rated capacity of a distribution substation can be calculated.

With all transformers in service, the substation utilization factor (UF) varies from 42% to 80%. Bolstad substation is the least loaded and Perche creek the most loaded substation, respectively. None of the substations are overloaded with all transformers in service (see Table 6).

Under N-1 condition, the substation's UF varies from 68% to 160%. Four of the seven substations would be overloaded for the loss of one transformer (see Table 6).

The following mitigation strategies may be considered if N-1 substation capacity adequacy is less than actual or forecast load:

- Adding a new transformer or larger transformers where substation overloading is expected to occur,
- Load transferring from overloaded to adjacent substations via distribution switching procedures,
- Developing a short term loss of life transformer rating procedure based on insulation degradation in conjunction with identifying available load transfers to defer substation transformer capacity additions,
- Add Energy Storage System (ESS) to shave peak demand conditions,

These capacity mitigation options will be covered as necessary in Section 3.1 and 5 of the present report to address any identified substation capacity adequacy shortfalls.

Table 6. Substation Capacity Assessment

Substation		Transformer		Load (MVA)	Category P0 (Non contingency)		Category P1 (N-1 Contingency)	
Name	ID	ID	Capacity (MVA)		Capacity (MVA)	UF	Capacity (MVA)	UF
Bolstad	BD	BD T1	22.40	18.8	44.80	42%	22.40	84%
		BD T2	22.40					
Blue Ridge	BR	BR T1	22.40	24.06	44.80	54%	22.40	107%
		BR T2	22.40					
Grindstone	GD	GD T1	22.40	36.21	67.20	54%	44.80	81%
		GD T2	22.40					
		GD T3	22.40					
Harmony Branch	HB	HB T1	22.40	27.40	44.80	61%	22.40	122%
		HB T2	22.40					
		HB T3	22.40	15.17	22.40	68%	00.00	Fails
Hinkson Creek	HC	HC T1	22.40	45.20	67.20	67%	44.80	101%
		HC T2	22.40					
		HC T3	22.40					
Perche Creek	PC	PC T1	22.40	35.81	44.80	80%	22.40	160%
		PC T2	22.40					
Power Plant	PL	PL T1	22.40	42.38	67.20	63%	44.80	95%
		PL T2	22.40					
		PL T3	22.40					
Rebel Hill	RH	RH T1	28.00	33.37	56.00	60%	28.00	119%
		RH T2	28.00					

2.2.2 Substation Transformer Load Factor (LF) and Utilization Factor (UF) Analysis

The load factor is the ratio of the energy loading that a piece of equipment is forecast to experience in operation in MWh divided by its maximum demand in MW times 8760 hours per year. It is used to assess how efficiently a transformer or circuit is utilized. It is defined as the relation between total kWh serviced in a period of time and the maximum demand over such a period of time, as expressed in Eq. 2-1. A low LF indicates the asset is infrequently loaded at rated capacity and high loading is of limited duration. High LF specifies the load could put a strain on the electrical system and the non-peak hour load is constantly high.

$$LF = \frac{\text{E−year (MWh)}}{\text{MD (MW)x 8,760 (Hrs)}} \qquad \text{(Eq. 2-1)}$$

Where:

LF	=	Load Factor
E-year	=	Energy consumed in a Year, expressed in MWh
MD	=	Maximum demand registered in the analyzed year, expressed in MW

Utilization factor (UF) is the ratio of the maximum load that could be drawn to the rated equipment/system capacity, as expressed in the following equation (Eq. 2-2):

$$UF = \frac{\text{MD (MVA or Amps)}}{\text{Capacity (MVA or Amps)}} \qquad \text{(Eq. 2-2)}$$

The average transformer's load factor (LF) is 48% with a maximum of 67% (Bosltad Transformer-1) and minimum of 37% (Perche Creek Transformer-1). Those values are typical for peer power utilities for industrial/commercial and residential service areas, respectively. Figure 3 shows the LF of all substation transformers.

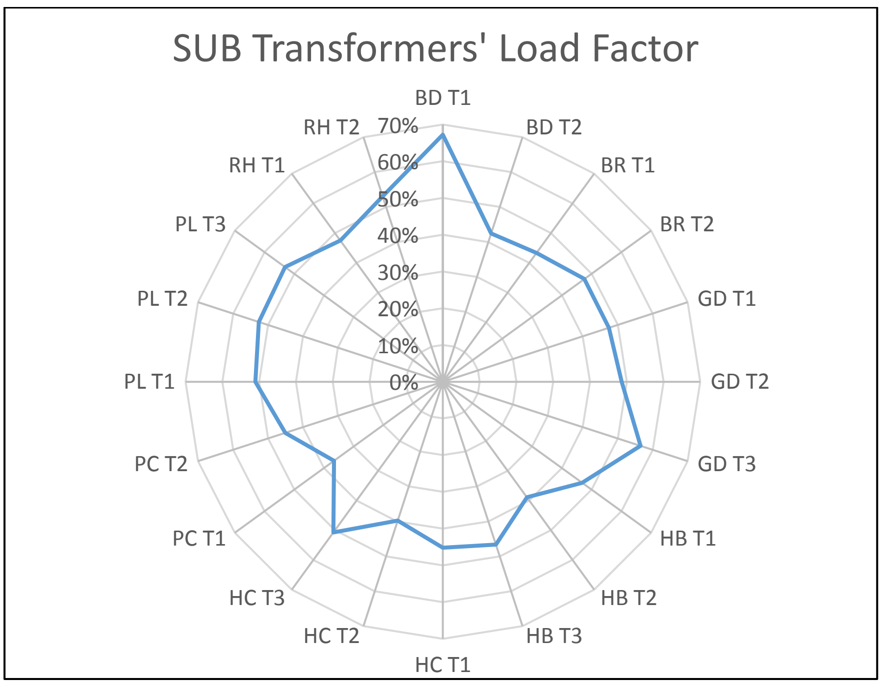


Figure 3. Distribution of substation transformer LF.

Transformer UF range from 32% to 81%. Perche Creek Transformer-1 registered the maximum value, while Blue Ridge Transformer-2 registered the minimum. See Figure 4 for transformers' UF

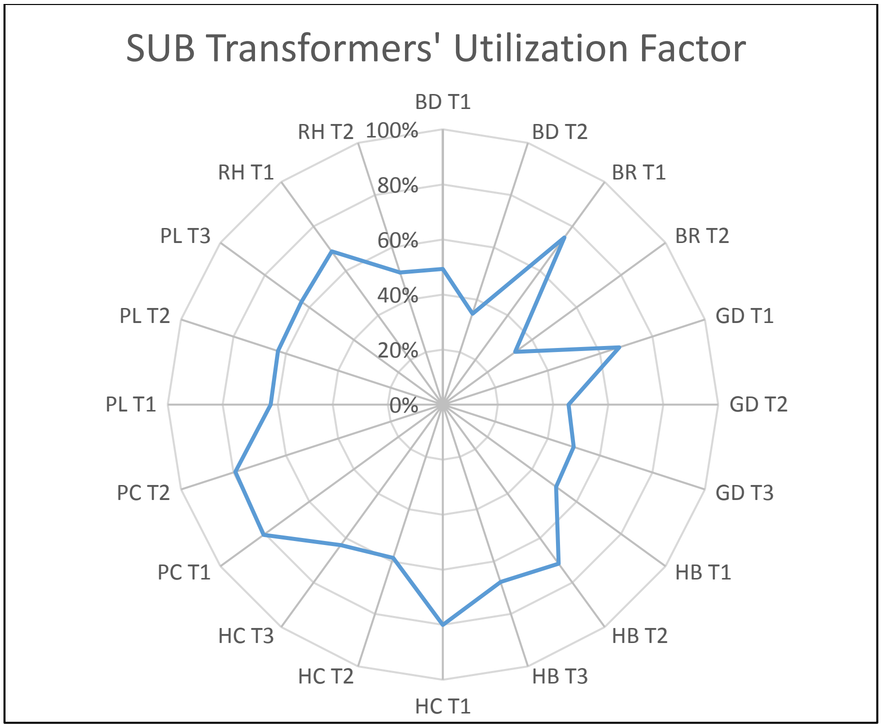


Figure 4. SUB transformers' UF.

Table 7 below summarizes the substation' transformers UF and LF indices. As shown in Figure 4 and Table 7, no transformer is overloaded under normal conditions.

Figure 5 shows the Perche Creek Transformer-1 load profile, the most heavily loaded transformer on the CWLD system. The recorded peak demand was 17.53 MVA. As observed, this transformer reaches its peak demand during July. For about 10 days of the year the load is above 15 MVA. During June, August and September the peak demand remains below 15 MVA (see Figure 6), and for the remaining eight months load, the transformer's peak demand is less than 10 MVA. Giving the high UF (81% for transformer 1), it is recommended to monitor the transformer load during July and create an offloading schedule that should be triggered in case Category P1 operation conditions occur (e.g. transformer failure)

Contrary to the high UF, Perche Creek Transformer 1 has the lowest LF indicating that this transformer provide service to mainly residential customers with very low load factor all together. The life cycle of the transformer is not impacted.

Load profiles figures for all transformers are presented in Appendix B.

Table 7. Substation Power Transformers' Performance (UF and LF)

Substation		Transformer		Load			UF	LF
Name	**ID**	**ID**	**Capacity**	**MW**	**MVAR**	**MVA**		
Bolstad	BD	BD T1	22.40	10.93	1.53	11.03	49%	67%
		BD T2	22.40	7.73	0.78	7.77	35%	42%
Blue Ridge	BR	BR T1	22.40	16.72	1.68	16.80	75%	43%
		BR T2	22.40	7.15	1.34	7.27	32%	48%
Grindstone	GD	GD T1	22.40	14.93	2.15	15.09	67%	47%
		GD T2	22.40	9.37	4.08	10.22	46%	49%
		GD T3	22.40	11.10	1.40	11.19	50%	57%
Harmony Branch	HB	HB T1	22.40	11.07	2.67	11.39	51%	47%
		HB T2	22.40	15.40	4.40	16.01	71%	39%
		HB T3	22.40	15.10	1.50	15.17	68%	47%
Hinkson Creek	HC	HC T1	22.40	17.80	2.20	17.94	80%	45%
		HC T2	22.40	13.00	1.90	13.14	59%	40%
		HC T3	22.40	13.90	2.60	14.14	63%	51%
Perche Creek	PC	PC T1	22.40	17.53	4.28	18.05	81%	37%
		PC T2	22.40	17.23	4.33	17.77	79%	45%
Power Plant	PL	PL T1	22.40	13.90	1.90	14.03	63%	51%
		PL T2	22.40	14.00	1.90	14.13	63%	53%
		PL T3	22.40	14.06	2.19	14.23	64%	53%
Rebel Hill	RH	RH T1	28.00	19.00	3.20	19.27	69%	47%
		RH T2	28.00	13.64	3.72	14.14	50%	53%

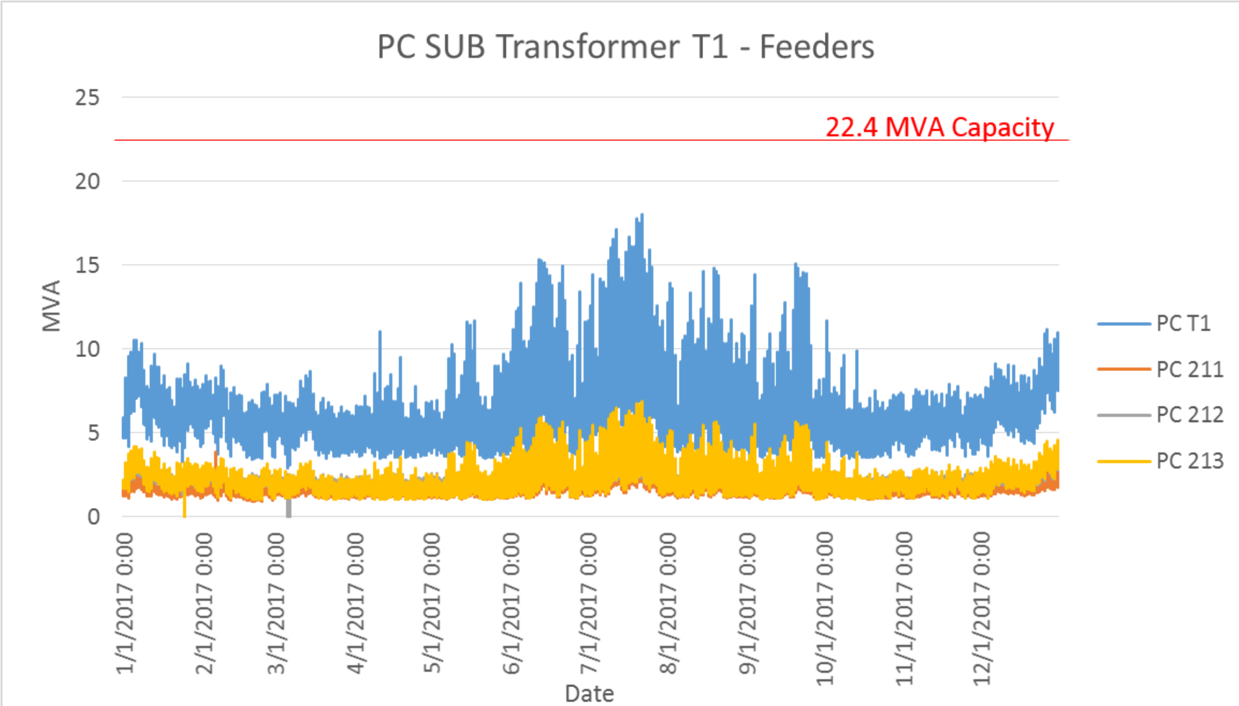


Figure 5. Perche Creek Transformer-1 and Distribution Circuits' Load Profile – Year 2017

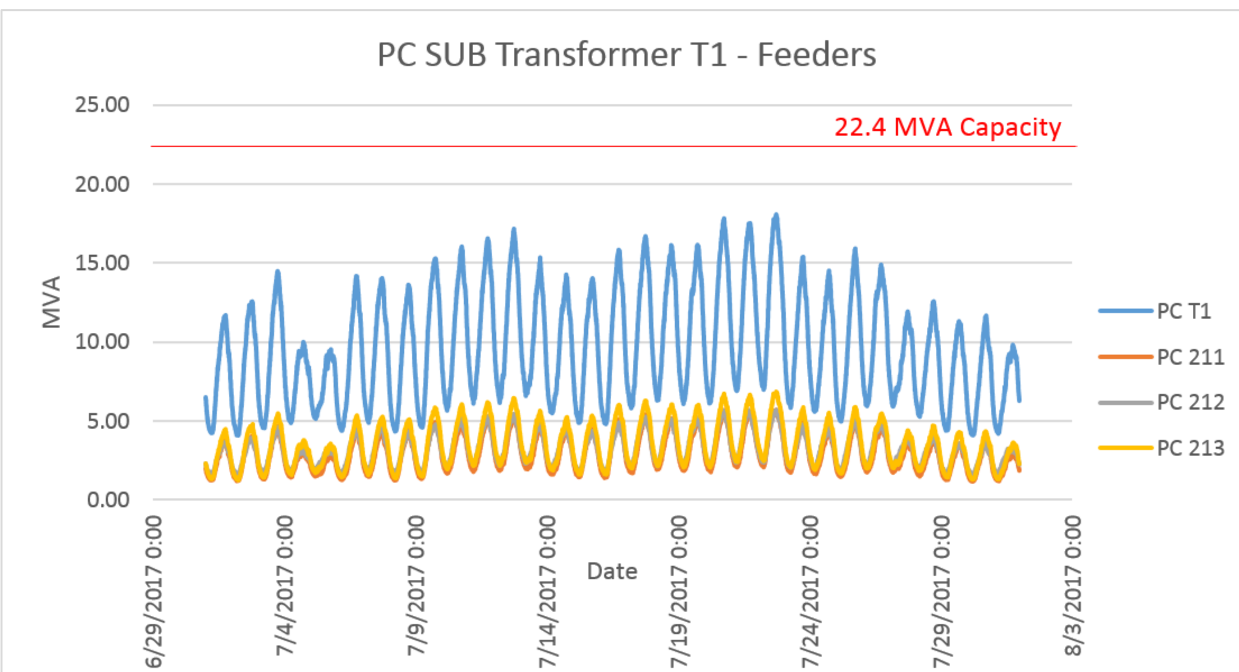


Figure 6. Perche Creek Transformer-1 and Distribution Circuits' Load Profile – July 2017

2.2.3 Distribution Circuit Load Factor Analysis

With the non-coincidental circuit peak demand, four distribution circuits registered load factors (LF) above 60% (BD-211, BD-213, PL-231 and RH-221). These are circuits feeding mainly industrial and/or commercial customers. Eleven circuits registered LFs between 50% and 60%. Close to 50% of the CWLD circuits (twenty seven) recorded LFs between 40% and 50%, typical values for mainly-residential service areas. There are sixteen circuits with LF below 40% with potential to increase its load without major system improvement work. Figure 7 and Figure 8 show the distribution of circuits based on LF. Table 8 list circuits with LF below 50%.

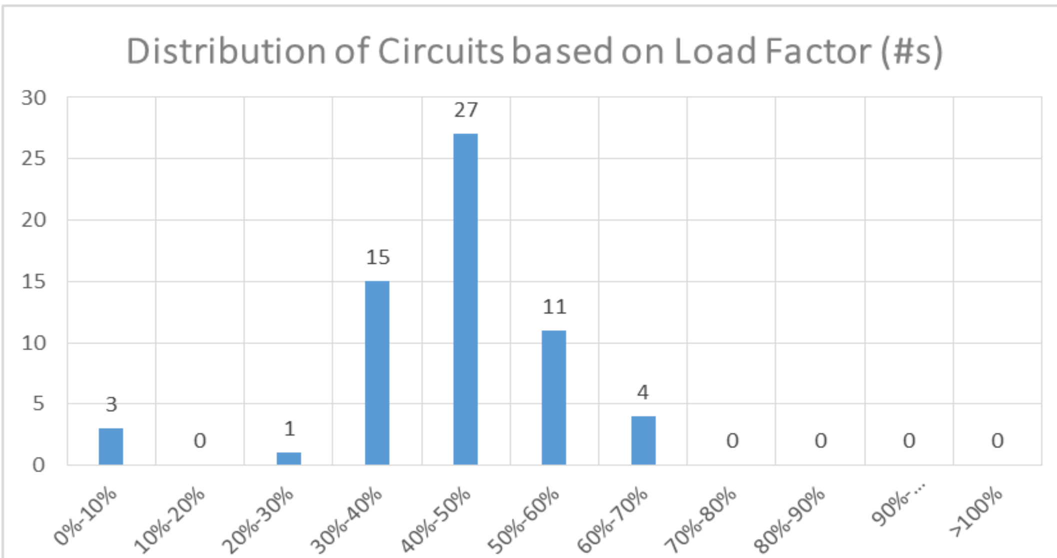


Figure 7. Distribution (expressed in numbers) of circuits based on their LF.

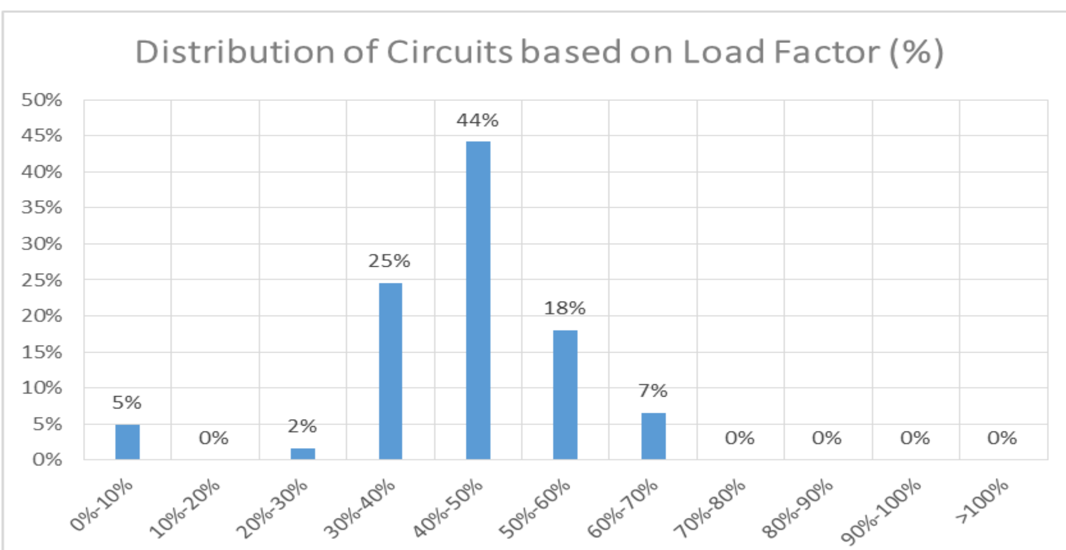


Figure 8. Distribution (expressed in %) of circuits based on LF.

Table 8. Circuits with LF below 50%

Circuit	LF
BD 223	28%
HB 223	32%
BR 212	33%
PC 211	34%
GD221	34%
PC 213	34%
PC 223	35%
HB 222	36%
RH 214	38%
BR 213	38%
HC 223	38%
HC 213	39%
PL 213	39%
HB 232	40%
HB 231	40%
HB 211	40%
PC 212	41%
BR 221	41%
RH 212	41%
RH 224	41%
HB 221	42%
BR 211	43%
HC 221	44%
PL 214	44%
PC 222	44%
HC 212	45%
GD211	45%
GD231	46%
PL 222	46%
PL 233	46%
PL 212	46%
PL 221	46%
HB 213	46%
HC 233	47%
PL 232	47%
HB 212	47%
PC 221	48%
GD212	48%
GD213	48%
BR 222	48%
HC 211	48%
HC 231	49%
HB 233	50%

2.3 Distribution Circuit Capacity Analysis

The CWLD has assumed 372 Amps to be the maximum circuit capacity for all 13.8-kV circuits. The published maximum allowed conductor temperature allowed by CWLD is 90 degrees Celsius. According to the National Electric Code the maximum current for the type of wire used by CWLD is 465 Amps. CWLD has decided that the maximum carrying capacity of this feeder shall not exceed 80% of the rated capacity of the feeder. This section presents an assessment of the calculated ampacity of all 13.8-kV circuits. To perform the ampacity study, CYMCAP (a CYME module) was used. CYMCAP deals with cables at all alternating voltages. Cables can be directly buried, in ducts/pipes, in backfills, in duct banks, in air, in troughs, or in casings. A circuit capacity depends upon, among others, the following factors:

1. Physical construction/cable geometry: direct buried, direct buried conduits, concrete encased duct bank, buried pipes, and cable in air
2. Ambient temperature
3. Circuit load factor
4. Cable specifications (by manufacturer)
5. Number of circuits in the same trench, etc.

The techniques and formulas outlined in the international standards IEC-60287©, IEC-60853©, and IEC-60949© issued by the International Electrotechnical Commission are used throughout the calculations. The permissible current rating of an AC cable is derived from the expression for the temperature rise above ambient temperature (See Eq. 2-3):

$$\Delta\theta = (I^2R + 0.5W_d)T_1 + (I^2R(1+\lambda_1) + W_d)nT_2 + (I^2R(1+\lambda_1+\lambda_2) + W_d)n(T_3+T_4) \quad \text{(Eq. 2-3)}$$

Where:

I	=	Current flowing in one conductor (A)
$\Delta\theta = \vartheta_c - \vartheta_{amb}$	=	Conductor temperature rise above ambient (°C)
R	=	ac resistance per unit length of the conductor at maximum operating temperature (Ω/m)
W_d	=	Dielectric loss per unit length for the insulation surrounding the conductor (W/m)
T_1	=	Thermal resistance per unit length between conductor and sheath (K·m/W)
T_2	=	Thermal resistance per unit length of the bedding between sheath and armour (K·m/W)
T_3	=	Thermal resistance per unit length of the external serving of the cable (K·m/W)
T_4	=	Thermal resistance per unit length between the cable surface and the surrounding medium (K·m/W)
n	=	Number of load-carrying conductors in the cable (equal size conductors carrying the same load)
λ_1	=	Ratio of losses in the metal sheath to total losses in all conductors in that cable

λ_2 = Ratio of losses in the armour to total losses in all conductors in that cable

Worst case scenarios for each substation's circuits were studied. The worst case scenario assumes four, three, or two circuits running in parallel in the same trench with no separation between conduits containing the circuits. The number of circuits running in the same trench is determined based on the graphical circuit maps provided by the CWLD. Table 9 list the circuits' IDs running in parallel in substation circuit's egress, together with the load factors that were used in the CYMCAP simulations.

Table 9. Number of Circuits in Circuit Egress per Substation

Number and Order of Circuits in an Egress Trench	LF
BD 212	56%
BD 213	62%
BR 221	41%
BR 211	43%
BR 212	33%
GD223	55%
GD222	52%
GD212	48%
GD221	34%
HB 231	40%
HB 223	32%
HB 211	40%
HB 233	50%
HC 213	39%
HC 212	45%
HC 223	38%
HC 211	48%
PC 213	34%
PC 222	44%
PC 221	48%
PC 223	35%
PL 233	46%
PL 212	46%
PL 221	46%
PL 232	47%
RH 221	61%
RH 222	51%
RH 223	0%
RH 224	41%

Figure 9 depicts the assumed circuit egress-trench layout for four, three or two circuits running in parallel. Four conduits is the most congested underground egress that CWLD has. CWLD indicated that the direct buried conduits are buried randomly with no separation between them.

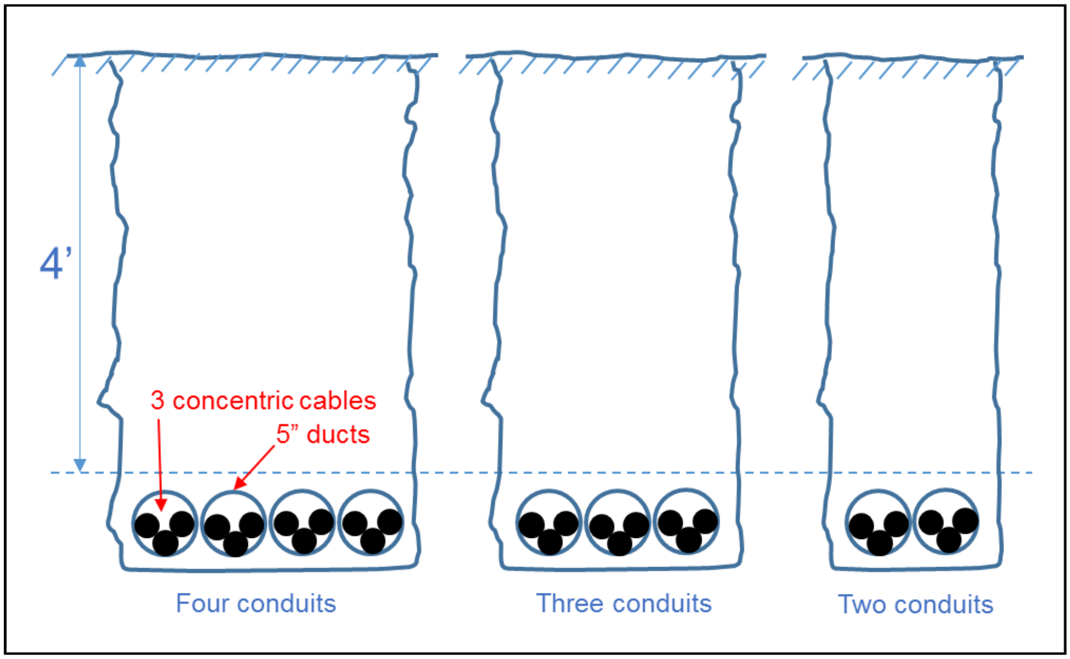


Figure 9. Cable layout in substation circuit egress trench.

The following technical factors were assumed:

1. Physical construction/cable geometry: direct buried conduits (5"), no separation between conduits, buried 4 feet deep. Four, three, or two conduits running in a trench.
2. Ambient temperature: 32 °C (90 °F).
3. Circuit load factor: depends on each circuit load profile.
4. Cable configuration: 500 kcmil, 15-kV type, 220 mils EPR 133% insulation, 1/3 concentric neutral with PVC jacket, single conductor.
5. Nominal capacity temperature: 105 °C (221 °F) (See cable sheet in Appendix C).
6. Emergency capacity temperature: 120 °C (248 °F) (Cable provider suggests 140 °C, see Appendix C).

2.3.1 Nominal capacity.

The ampacity study results show that the circuit's capacity are greater than the assumed capacity (352 Amps). The increase varies from 15 to 58 Amps (4% to 16%, respectively). The increase in capacity is due to two factors: 1) circuit load factor (LF ≤ 62%) and 2) the number of circuits in an egress trench (four at the most). The lower the load factor and the fewer circuits in a trench, the greater the circuit capacity can be. Table 10 depicts the ampacity study results.

Table 10. Circuit Ampacity Study Result

Circuit order in trench	LF	Calculated Capacity @ 105 °C	
		Amps	kVA
BD 212	56%	398	9,513
BD 213	62%	398	9,513
BR 221	41%	410	9,800
BR 211	43%	410	9,800
BR 212	33%	410	9,800
GD223	55%	367	8,772
GD222	52%	367	8,772
GD212	48%	367	8,772
GD221	34%	367	8,772
HB 231	40%	386	9,226
HB 223	32%	386	9,226
HB 211	40%	386	9,226
HB 233	50%	386	9,226
HC 213	39%	384	9,178
HC 212	45%	384	9,178
HC 223	38%	384	9,178
HC 211	48%	384	9,178
PC 213	34%	386	9,226
PC 222	44%	386	9,226
PC 221	48%	386	9,226
PC 223	35%	386	9,226
PL 233	46%	373	8,915
PL 212	46%	373	8,915
PL 221	46%	373	8,915
PL 232	47%	373	8,915
RH 221	61%	394	9,417
RH 222	51%	394	9,417
RH 223	0%	394	9,417
RH 224	41%	394	9,417

To ensure safe system operation, all circuits coming out of a substation will assume the calculated circuit capacity for such a substation. Table 11 (BD, BR, GD and HB circuits) and Table 12 (HC, PC, PL, RH circuits) present the assumed circuit capacity and the calculated (revised) circuit capacity.

Table 11. Assumed and Calculated Circuit Capacity (BD, BR, GD and HB circuits)

Circuit	Assumed Capacity (Amps)	Calculated Capacity @ 105 °C (Amps)
BD 212	372	398
BD 213	372	398
BD 211	372	398
BD 221	372	398
BD 222	372	398
BD 223	372	398
BR 221	372	410
BR 211	372	410
BR 212	372	410
BR 213	372	410
BR 222	372	410
GD223	372	367
GD222	372	367
GD212	372	367
GD221	372	367
GD211	372	367
GD213	372	367
GD231	372	367
GD232	372	367
GD233	372	367
HB 231	372	386
HB 223	372	386
HB 211	372	386
HB 233	372	386
HB 212	372	386
HB 213	372	386
HB 221	372	386
HB 222	372	386
HB 232	372	386

Table 12. Assumed and Calculated Circuit Capacity (HC, PC, PL and RH circuits)

Circuit	Assumed Capacity (Amps)	Calculated Capacity @ 105 °C (Amps)
HC 213	372	384
HC 212	372	384
HC 223	372	384
HC 211	372	384
HC 221	372	384
HC 222	372	384
HC 231	372	384
HC 232	372	384
HC 233	372	384
PC 213	372	386
PC 222	372	386
PC 221	372	386
PC 223	372	386
PC 211	372	386
PC 212	372	386
PL 233	372	373
PL 212	372	373
PL 221	372	373
PL 232	372	373
PL 213	372	373
PL 214	372	373
PL 222	372	373
PL 223	372	373
PL 231	372	373
RH 221	372	394
RH 222	372	394
RH 223	372	394
RH 224	372	394
RH 211	372	394
RH 212	372	394
RH 213	372	394
RH 214	372	394

2.3.2 Emergency Capacity

Considering the expensive – sometimes prohibitive – cost of replacing failed cables during emergency operation, power utilities do not risk cable loading beyond 120 °C operating temperature. Most utilities allow no more than 4 hours of continuous operation at emergency loading conditions. Should circuit load increase beyond the emergency ratings or see continuous operation beyond 4 hours, the distribution system operator coordinates load shedding or load transferring. Table 13 shows circuits' emergency capacities at 120°C of BD, BR, GD and HB circuits.

Table 13. Calculated Circuit Emergency Capacity (BD, BR, GD and HB circuits)

Circuit	Calculated Emergency Capacity @ 120 °C	
	Amps	kVA
BD 212	434	10,373
BD 213	434	10,373
BD 211	434	10,373
BD 221	434	10,373
BD 222	434	10,373
BD 223	434	10,373
BR 221	448	10,708
BR 211	448	10,708
BR 212	448	10,708
BR 213	448	10,708
BR 222	448	10,708
GD223	401	9,585
GD222	401	9,585
GD212	401	9,585
GD221	401	9,585
GD211	401	9,585
GD213	401	9,585
GD231	401	9,585
GD232	401	9,585
GD233	401	9,585
HB 231	423	10,110
HB 223	423	10,110
HB 211	423	10,110
HB 233	423	10,110
HB 212	423	10,110
HB 213	423	10,110
HB 221	423	10,110
HB 222	423	10,110
HB 232	423	10,110

Table 14 shows circuits' emergency capacities at 120ºC of HC, PC, PL, RH circuits.

Some utilities do not consider emergency ratings and only use the circuit nominal capacity for both normal and emergency distribution system operation.

Table 14. Calculated Circuit Emergency Capacity (HC, PC, PL and RH).

Circuit	Calculated Emergency Capacity @ 120 °C	
	Amps	kVA
HC 213	420	10,039
HC 212	420	10,039
HC 223	420	10,039
HC 211	420	10,039
HC 221	420	10,039
HC 222	420	10,039
HC 231	420	10,039
HC 232	420	10,039
HC 233	420	10,039
PC 213	425	10,158
PC 222	425	10,158
PC 221	425	10,158
PC 223	425	10,158
PC 211	425	10,158
PC 212	425	10,158
PL 233	408	9,752
PL 212	408	9,752
PL 221	408	9,752
PL 232	408	9,752
PL 213	408	9,752
PL 214	408	9,752
PL 222	408	9,752
PL 223	408	9,752
PL 231	408	9,752
RH 221	431	10,302
RH 222	431	10,302
RH 223	431	10,302
RH 224	431	10,302
RH 211	431	10,302
RH 212	431	10,302
RH 213	431	10,302
RH 214	431	10,302

2.3.3 Distribution Circuit Utilization Factor (UF) Analysis

Utilization factor (UF) is defined as the relation between circuit maximum load observed at the head of the circuit and the circuit capacity (as defined in Section 2.3 above). With the circuit capacity assumed by the CWLD as base (8.89 MVA), circuit HC 223 was identified as the most loaded at peak demand with a UF of 98%. Statistically, 27% of distribution circuits recorded a UF above 70%, while 33% of distribution circuits registered loading below 50% UF as illustrated in Figure 10. Transformer and circuit peak demand are listed in Appendix D.

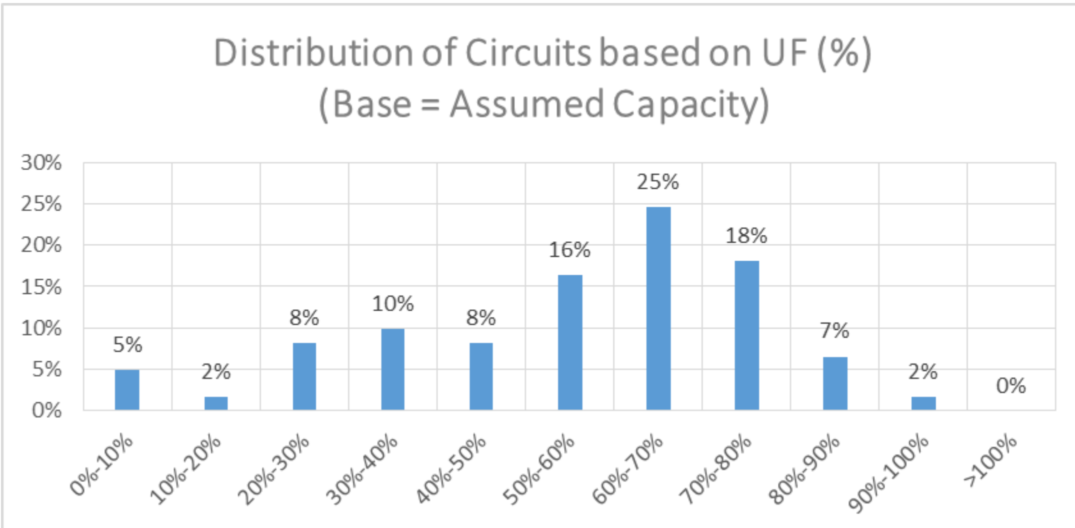


Figure 10. Distribution (expressed in %) of circuits based on their utilization factor – Assumed Capacity.

With the calculated circuit capacity result as base, the most-loaded circuit registered a UF of 95% (all circuits shifted toward lower levels of UF). The number of circuits with UF greater than 70% reduced to 15% (from 27%). Circuits with UF below 50% increased to remains statically the same (33%).

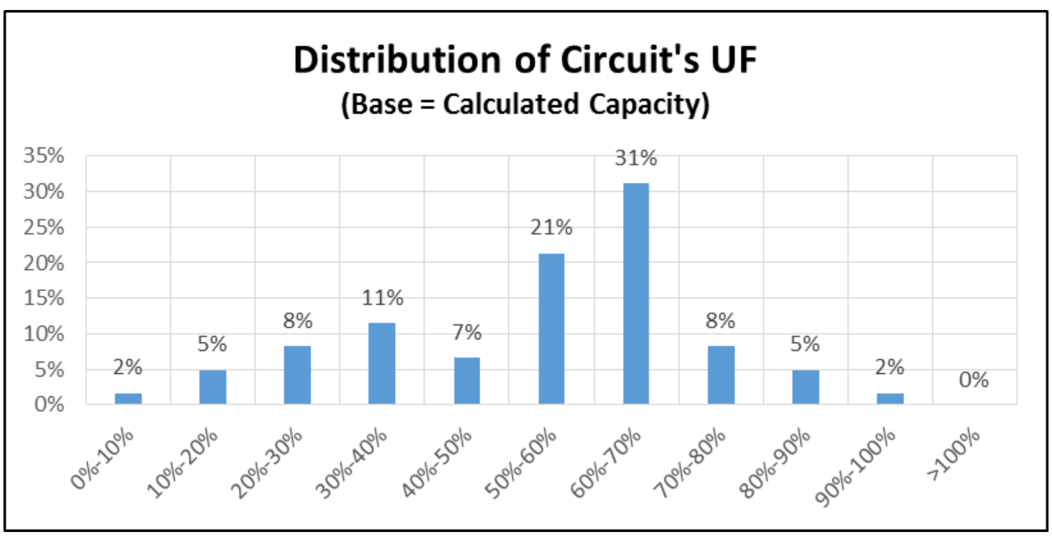


Figure 11. Distribution (expressed in %) of circuits based on their utilization factor – Calculated Capacity.

With the calculated circuit capacity, no distribution circuit registered overloading concerns and loading factor decreases except circuit of Grindstone substation which UF increases by 1%. In Table 15 and Table 16, the red bars represent circuit's UF with assumed capacity as base while the blue bars shows the circuit's UF with calculated capacity as base. Table 15 illustrates UF for BD, BR, GD and HB circuits. Table 16 depicts the UF for HC, PC, PL and RH circuits.

Table 15. UF Comparison for BD, BR, GD and HB Circuits

Circuit	Assumed Capacity			Calculated Capacity (@ 105^{o}C)		
	Amps	kVA	U.F.	Amps	kVA	U.F.
BD 212	372	8,891	46%	398	9,513	43%
BD 213	372	8,891	71%	398	9,513	66%
BD 211	372	8,891	24%	398	9,513	23%
BD 221	372	8,891	13%	398	9,513	12%
BD 222	372	8,891	73%	398	9,513	68%
BD 223	372	8,891	74%	398	9,513	69%
BR 221	372	8,891	16%	410	9,800	14%
BR 211	372	8,891	67%	410	9,800	61%
BR 212	372	8,891	74%	410	9,800	67%
BR 213	372	8,891	77%	410	9,800	70%
BR 222	372	8,891	68%	410	9,800	61%
GD223	372	8,891	25%	367	8,772	25%
GD222	372	8,891	39%	367	8,772	40%
GD212	372	8,891	67%	367	8,772	68%
GD221	372	8,891	63%	367	8,772	64%
GD211	372	8,891	74%	367	8,772	75%
GD213	372	8,891	36%	367	8,772	37%
GD231	372	8,891	28%	367	8,772	29%
GD232	372	8,891	69%	367	8,772	70%
GD233	372	8,891	38%	367	8,772	39%
HB 231	372	8,891	47%	386	9,226	45%
HB 223	372	8,891	57%	386	9,226	55%
HB 211	372	8,891	23%	386	9,226	22%
HB 233	372	8,891	66%	386	9,226	64%
HB 212	372	8,891	41%	386	9,226	40%
HB 213	372	8,891	67%	386	9,226	64%
HB 221	372	8,891	61%	386	9,226	59%
HB 222	372	8,891	72%	386	9,226	69%
HB 232	372	8,891	66%	386	9,226	64%

Table 16. UF Comparison for HC, PC, PL and RH Circuits

Circuit	Assumed Capacity			Calculated Capacity (@ 105°C)		
	Amps	kVA	U.F.	Amps	kVA	U.F.
HC 213	372	8,891	61%	384	9,178	59%
HC 212	372	8,891	72%	384	9,178	70%
HC 223	372	8,891	98%	384	9,178	95%
HC 211	372	8,891	78%	384	9,178	75%
HC 221	372	8,891	55%	384	9,178	53%
HC 222	372	8,891	11%	384	9,178	11%
HC 231	372	8,891	57%	384	9,178	55%
HC 232	372	8,891	50%	384	9,178	49%
HC 233	372	8,891	63%	384	9,178	61%
PC 213	372	8,891	77%	386	9,226	74%
PC 222	372	8,891	60%	386	9,226	58%
PC 221	372	8,891	90%	386	9,226	87%
PC 223	372	8,891	54%	386	9,226	52%
PC 211	372	8,891	64%	386	9,226	62%
PC 212	372	8,891	64%	386	9,226	62%
PL 233	372	8,891	56%	373	8,915	56%
PL 212	372	8,891	47%	373	8,915	47%
PL 221	372	8,891	52%	373	8,915	52%
PL 232	372	8,891	55%	373	8,915	55%
PL 213	372	8,891	80%	373	8,915	80%
PL 214	372	8,891	69%	373	8,915	69%
PL 222	372	8,891	40%	373	8,915	40%
PL 223	372	8,891	82%	373	8,915	82%
PL 231	372	8,891	55%	373	8,915	55%
RH 221	372	8,891	40%	394	9,417	37%
RH 222	372	8,891	90%	394	9,417	85%
RH 223	372	8,891	1%	394	9,417	1%
RH 224	372	8,891	38%	394	9,417	36%
RH 211	372	8,891	84%	394	9,417	79%
RH 212	372	8,891	54%	394	9,417	51%
RH 213	372	8,891	28%	394	9,417	26%
RH 214	372	8,891	62%	394	9,417	58%

2.3.4 Load Modeling in Cyme Power Flow Model.

The non-coincidental circuit peak demand was used to perform load allocation to each modeled service transformer. The load allocation to each service transformer was performed using the following equation:

$$LTi. = \frac{Circuit\ Load * Ti\ capacity}{\sum_{1}^{n} Ti\ Capacity}$$

Where:

LTi.	=	Load allocated to service transformer i
Circuit Load	=	Non-coincidental circuit peak demand (MVA, PF)
Ti	=	Capacity of Service transformer i (MVA)
$\sum_{1}^{n} Ti\ Capacity$	=	Sum of circuit service transformer capacity (MVA)

Before performing load allocation, all spot-loads values were fixed so that they are included in the total peak demand.

3 DISTRIBUTION SYSTEM PERFORMANCE

3.1 Substation Transformer Rating Methodologies

Quanta Technology would recommend consideration of one of three ratings methodologies to apply to the total capacity of a load serving substation to address actual or forecast capacity shortfalls. Two of these options provide for the opportunity to defer transformer capacity additions. The methodology which the CWLD selects will be based on the level of risk tolerance which they have regarding substation operation. The three methods of rating load serving substations are:

- N-1 transformer nameplate capacity based on the maximum nameplate rating of the transformers
- N-1 transformer nameplate capacity plus the maximum load that can be transferred to a neighboring substation(s) based on the adjacent substations N-0 capacity and the available feeder capacity to facilitate load transfers
- N-1 transformer acceptable loss of life capacity, for example a 2% loss of life overload rating derived from the manufacturer's nameplate and heat run data. The loss of life is a function of assumed transformer insulation degradation. A loss of life rating could be combined with load transfers to adjacent substations.

3.1.1 N-1 Transformer Nameplate Capacity

This approach is the most conservative. The basic assumption is that the low side of a load serving substation could be tied together in such a way that, for the outage of one of the substation's transformers, the remaining transformer(s) could share the load equally or as determined by the transformers' impedance.

Thus a substation with two 22.5 MVA transformers with a low side bus operated normally open would be rated a total of 22.5 MVA based on the outage of one transformer and closing the necessary low side bus-tie breakers. A substation with three 22.5 MVA transformers with the low side buses operated normally open would be rated a total of 45 MVA based on the outage of one transformer and closing the necessary low side bus-tie breakers. The rating in this method is determined by the sum of the capacity of the smallest remaining transformers.

3.1.2 N-1 Transformer Nameplate Capacity plus Load Transfer

This ratings method augments the previous approach by including the amount of load that can be transferred to an adjacent substation or substations via feeder switching. The magnitude of feeder load that can be transferred is a function of:

1) The total number of feeders that can have all or some of their loads transferred to an adjacent substation.
2) The location of sectionalizing devices on the feeders which are available to facilitate post contingency load transfers.
3) The magnitude of the load to be transferred based on the location of the sectionalizing devices.
4) The feeder capacity and voltage constrained load carrying capability of the feeders out of the adjacent substation which will be used to transfer load; and

5) The N-0 transformer capacity of the adjacent substations which will be accepting load transfers.

The implementation of this ratings methodology requires a case by case review of bullets one through four. This review is required to determine the potential load that can be transferred away and the ability of the feeders and transformers at the adjacent substations to accept the load to be transferred. The feeder capacity used in evaluating the ability to accept load transfers from adjacent substation can be increased if a short term emergency rating is used to determine feeder capacity.

The amount of load that can be transferred to the feeders of an adjacent substation is limited by the applicable rating of the transformer which supplies the feeder(s) to which load is transferred assuming that no 13.8kV bus tie breakers are closed. This limits exposure to N-1-1 contingency events should a bus tie breaker failure occur. Additionally, it is assumed that overlapping transformer outages involved in the load transfers do not occur at adjacent substations. Closing low side bus tie breakers to increase the available transformer of the receiving substation is possible but would increase the load at risk for a follow on contingency.

3.1.3 N-1 Acceptable Loss of Life plus Load Transfer

This method is an extension of the N-1 substation capacity plus load transfer. In this approach the N-1 substation transformer capacity is assumed to be greater than the maximum nameplate value. Manufacture transformer nameplate and heat run data would be used to determine the relationship between the maximum top oil temperature and forecast loss of life using software such as the EPRI PTLoad program. Loss of life is an estimation of degradation of the transformer insulation due to high temperature operation. The acceptable loss of life emergency rating is an MVA rating which considers ambient conditions, an assumed daily load cycle, and the long term effect on transformer insulation life. The acceptable loss of life rating would be based on risk tolerance and transformer outage performance. Operational metrics, such as maximum top oil temperature and/or an associated maximum percentage of 65^{o}C overload, could be developed to provide guidance as to when load curtailments might be required.

The following is an example of how transformer test data and the EPRI PTLoad program could be used to calculate an emergency transformer rating based on an acceptable loss of life. Input data for this example were obtained from the Waukesha transformer test report provided by the CWLD and augmented with some approximations that would typically be obtained from the transformer nameplate. The calculations assumed a constant 35^{o}C ambient temperature over 24 hours and a daily load cycle for which the transformer was loaded to 125% of its 65^{o}C rise rating of 22.5 MVA, 28 MVA, for five hours with a minimum load of 75% of nameplate (Figure 12). In this calculation the transformer is assumed to have a 20.55 year life (180,000 hours).

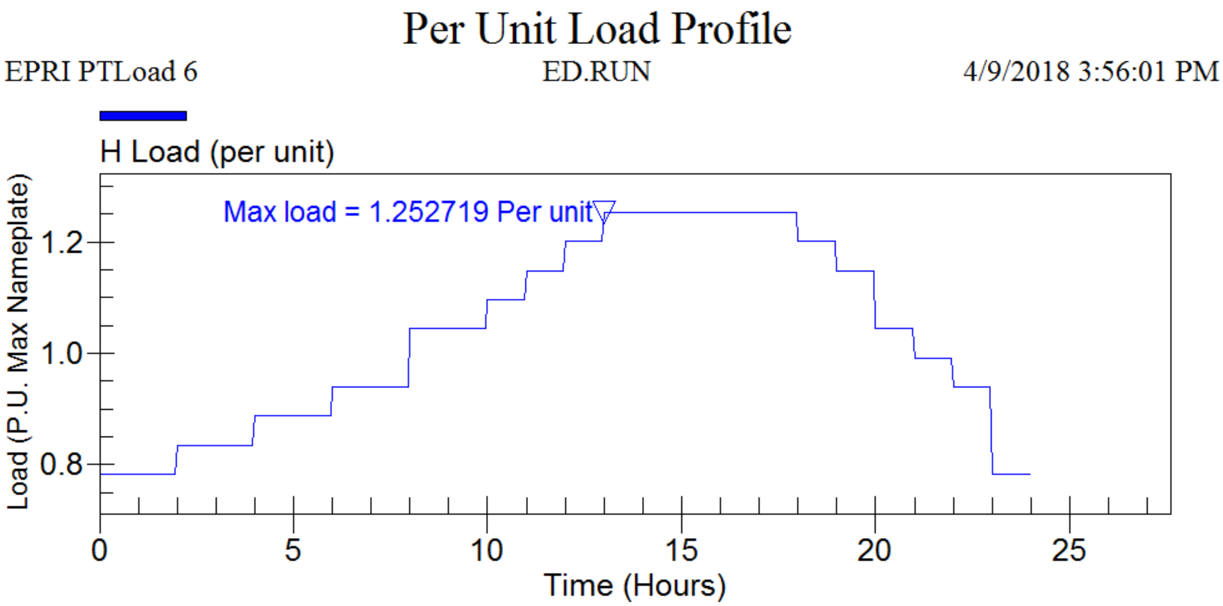


Figure 12. 22.5 MVA transformer load profile

For these ambient and loading conditions the PTLoad program calculated a top oil temperature of 106.4°C and a hot spot temperature of 150°C (Figure 13). The cumulative loss of life over the course of a 24 hour period for these conditions is 0.14%. Operating at or below the transformer rating would have a calculated loss of life of 24 hours or 0.013% over its 180,000 hour assumed life (Figure 14). To limit the increase in transformer loss of life to 2.0%, additional transformer capacity would need to be installed within approximately 14 days so as to return the maximum transformer loading to below the 22.5 MVA 65°C rise rating.

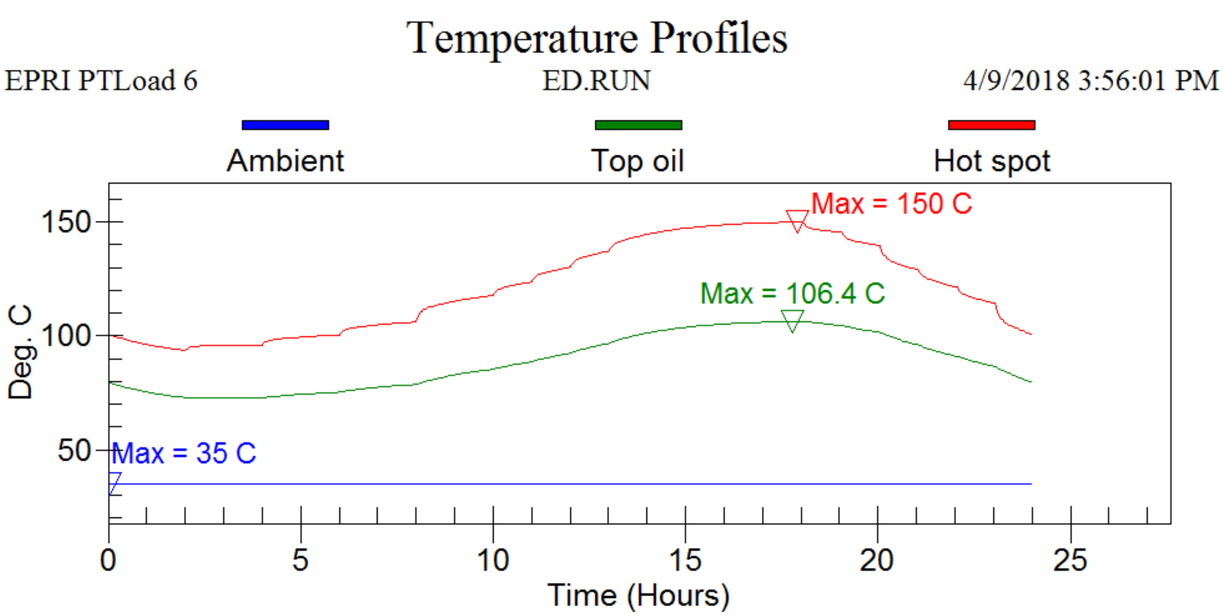


Figure 13. 22.5 MVA transformer temperature profile

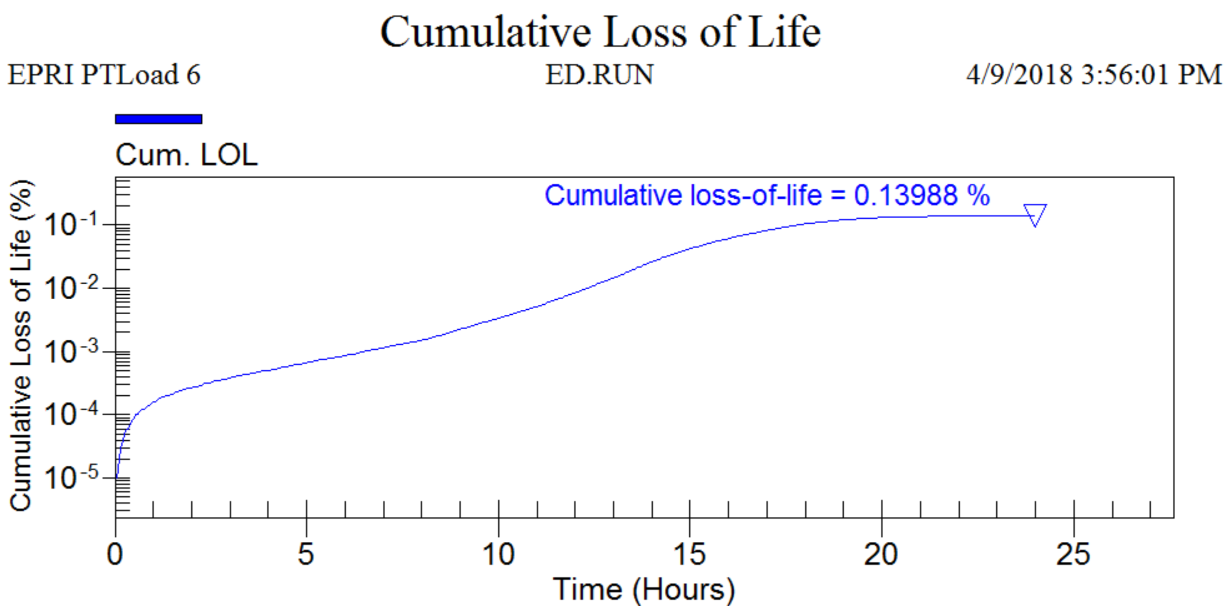


Figure 14. 22.5 MVA transformer cumulative loss of life

Based on these generic calculations, a 22.5 MVA transformer would have a 14 day, 2% loss of life rating of 28 MVA. The risk assessment associated with this type of short term, loss of life rating should include both the probability of a transformer outage, assumed to be roughly 4% for this example, and the probability at being at or near peak load conditions, roughly 5% based on generic load duration assumptions. Thus the probability of a transformer outage at or near peak conditions is roughly 0.2%. The possibility of overlapping transformer outages of units that reserve each other under peak load conditions is assumed to be very small.

The use of this type of emergency loss of life rating and load transfer would provide additional operational flexibility and reduce the current exposure to contingency based load curtailments. The application of such short term substation capacity ratings would also provide the opportunity to defer substation transformer capacity additions or other remedies suggested by the substation overloads identified in Table 6. Actual transformer data should be used to calculate the loss of life data for either classes of transformers or individual transformers.

As noted previously, the application of a loss of life overload rating is subject to risk tolerance associated with several factors. These would include the age of the transformers, the current condition of the transformers (e.g. subject to high levels of combustible gasses), the ability and time required to perform feeder to feeder load transfers, and the availability of spare transformers and the time required to install a replacement. All of these factors should be considered before applying transformer loss of life in the assessment of substation transformer capacity adequacy. While the application of a loss of life rating may prove to be unacceptable in the adequacy planning, a detailed assessment of the CWLD transformer population would provide a metric, such as maximum allowable top oil temperature as an indicator of transformer degradation, which could be used operationally to assess the risk of overloads as an alternative to load curtailment.

3.2 Distribution System Thermal Capacity

Thermal capacity analysis tests the ability of each system element, beyond the circuit head, (feeder section, service transformer, switches, voltage regulators, etc.) to carry power during the circuit peak demand. It compares the maximum power flow through a system element with the system element's nominal capacity. This metric is the thermal capacity ratio and it is expressed as follows (Eq. 3-1):

$$Thermal\ Capacity\ ratio\ (\%) = \frac{Maximum\ current\ through\ system\ element\ \ (Amps)}{System\ element\ nominal\ capacity\ (Amps)} \qquad \text{(Eq. 3-1)}$$

Based on the loading data provided, the CWLD distribution system did not experience any overloads at the time of circuit peak demand with all substation transformers and 13.8-kV distribution circuits in service. Figure 15 shows the calculated maximum thermal capacity ratio (loading capacity) of each of the 60 distribution circuits analyzed. The "Y" axis represents the maximum thermal capacity (expressed in %) of each of the analyzed circuits. The "X" axis represent each of the 60 circuits

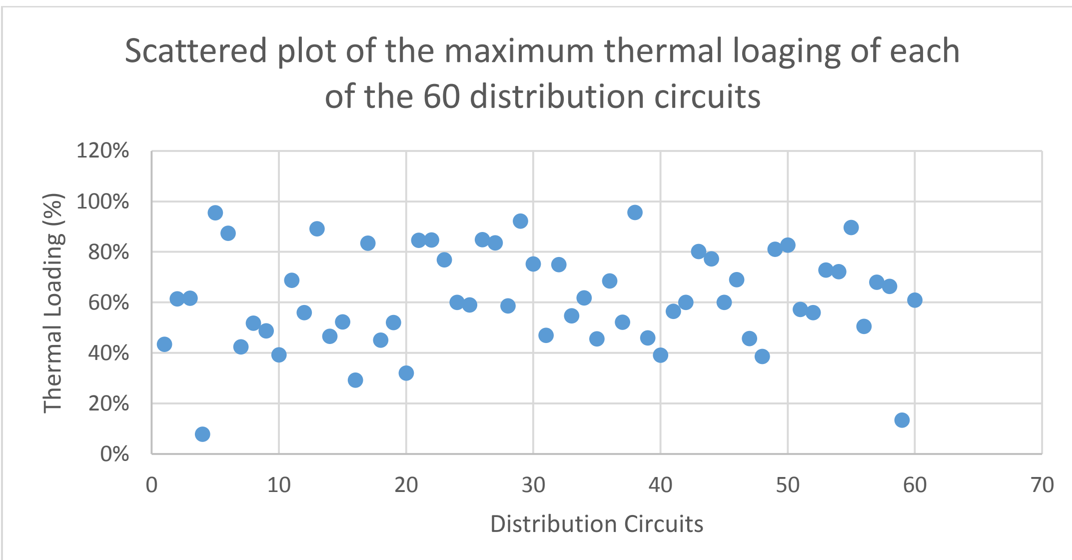


Figure 15. Distribution System, scattered plot maximum Thermal Loading of each circuit.

3.3 Distribution System Voltage Performance

ANSI C84.1 Standard defines voltage levels for utilization and service voltages (see Figure 16). The utilization voltage is the voltage level needed for proper operation of customer appliances and fixtures. The service voltage is the voltage level the power utility is expected to provide to their customers at their service entrance.

The ANSI standard defines "Range A" and "Range B" voltages for normal and emergency (infrequent) system operation conditions:

- Range A, the occurrence of service voltage outside of these limits should be infrequent. Utilization equipment shall be designed to give satisfactory performance throughout Range A voltages.
- Range B, Voltage levels as a result of practical design and operating conditions, they shall be limited in extent, frequency, and duration. When occurrence is sustained, corrective measurement shall be undertaken to meet Range A requirements

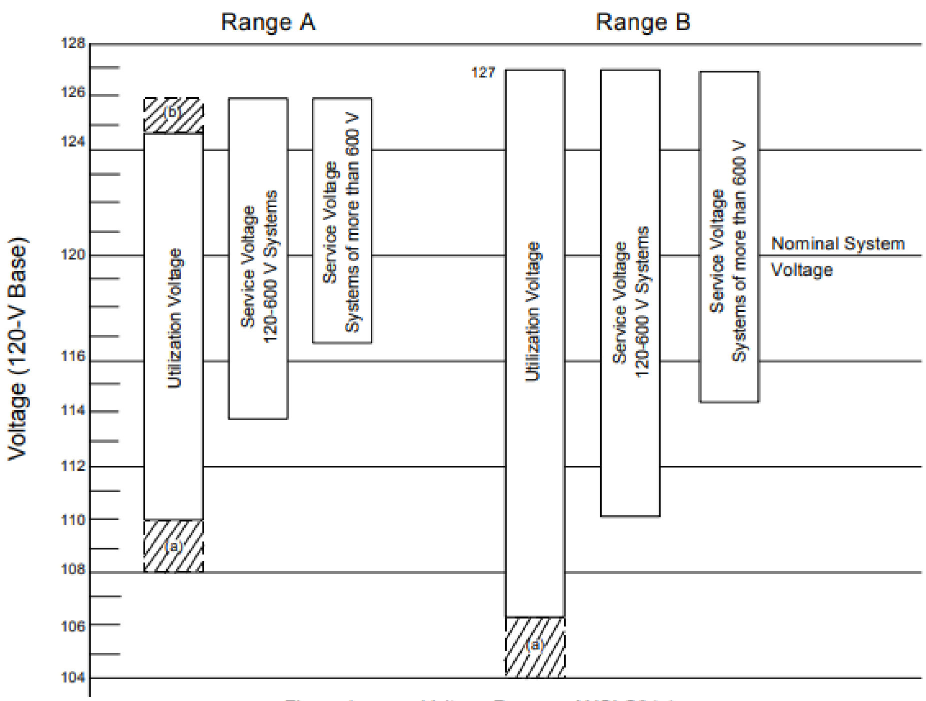


Figure 1. Voltage Ranges, ANSI C84.1

NOTES:
(a) These shaded portions of the ranges do not apply to circuits supplying lighting loads
(b) This shaded portion of the range does not apply to 120-600-volt systems.
(c) The difference between minimum service and minimum utilization voltages is intended to allow for voltage drop in the customer's wiring system. This difference is greater for service at more than 600 volts to allow for additional voltage drop in transformations between service voltage and utilization equipment.

Figure 16. ANSI C84.1 Voltage Level Standard

The CYME distribution system model includes service transformers, which typically accounts for voltage drop of 3 V on a 120 V base. As shown in Table 17, in the 120 standard voltage column, the minimum voltage level at the secondary side of a service transformer should be 114 V (95% of 120 V nominal) during circuit peak demand condition, and the maximum voltage level at the service entrance should not exceed 126 V (120 V +/- 5%).

Table 17. Voltage Levels and Different Voltage Standards

Voltage Point of Measurement		Standard Voltages (V)						Percent of Nominal Voltage
		120	208	240	277	480	600	
Service Entrance Voltage	High Voltage Range A	126	218	252	291	504	630	105.0%
	Low Voltage Range A	114	198	228	263	456	570	95.0%
	High Voltage Range B	127	220	254	293	508	635	105.8%
	Low Voltage Range B	110	191	220	254	440	550	91.7%
Utilization Voltage	High Voltage Range A	126	218	252	291	504	630	105.0%
	Low Voltage Range A	108	187	216	249	432	540	90.0%
	High Voltage Range B	127	220	254	293	508	635	105.8%
	Low Voltage Range B	104	180	208	240	416	520	86.7%

During peak demand condition, all circuits – except circuit PC 221 – comply with ANSI voltage standards. The straight dotted red lines in Figure 17 show the maximum and minimum ANSI voltage levels (105% and 95% respectively). It also shows the maximum and minimum voltages from power flow modeling for each distribution circuit. The maximum voltage levels are presented in dark-colored solid lines, while minimum voltage levels are presented in light-colored dotted lines. The "X" axis represents each of the 60 circuits. As observed, the minimum voltage is 112.4 V (93.7% of nominal value), which was identified in one node of the circuit PC 221.

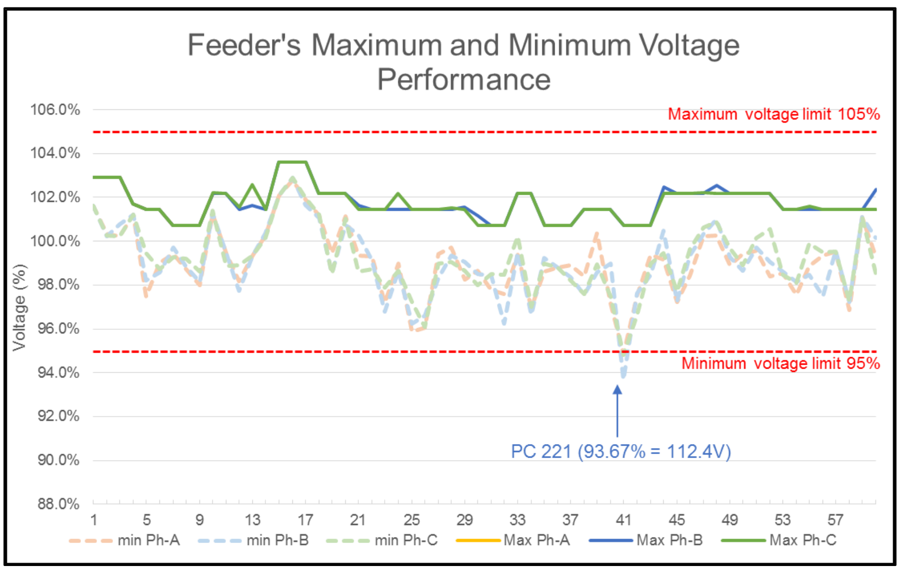


Figure 17. Maximum and minimum voltage of each distribution circuit.

Figure 17 allows for the identification of voltage violation (voltage below 95% of nominal voltage for this case). Figure 18 locates circuit sections with voltage violation (voltages below 95%), which are shown as red lines.

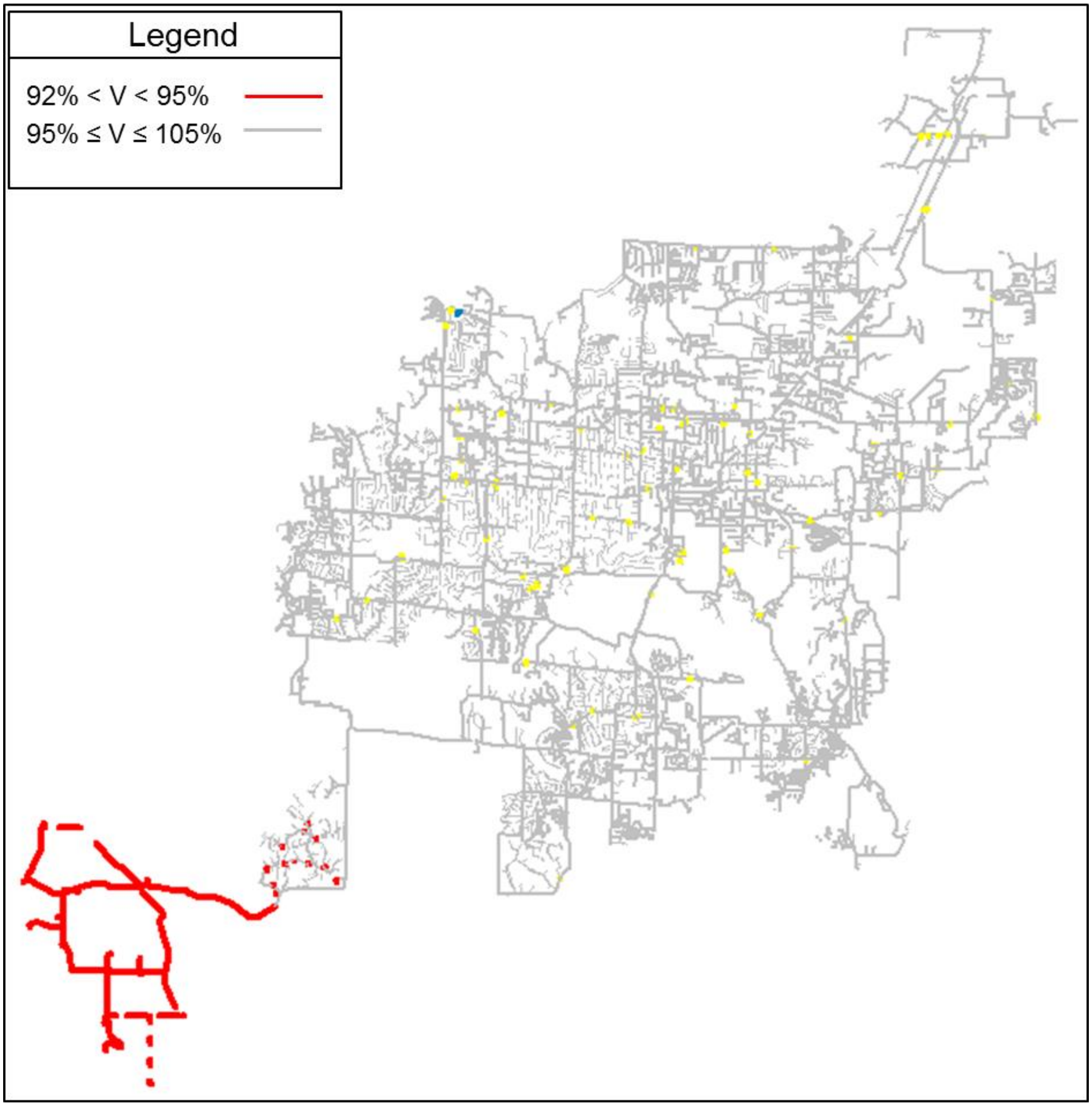


Figure 18. Voltage level color code map

Table 18 list the maximum and minimum voltage values calculated by the power flow modeling in circuit PC 221 during peak demand conditions.

Table 18. Maximum and Minimum Voltage – Circuit PC 221

Minimum Voltage			Maximum Voltage		
min Ph-A	min Ph-B	min Ph-C	Max Ph-A	Max Ph-B	Max Ph-C
94.83%	93.67%	94.81%	100.72%	100.72%	100.72%

As stated in the ANSI C84.1 standard, Range B voltage levels shall be limited in extent, frequency, and duration. A closer view identified that, when the circuit load in circuit PC 221 is 6.5 MVA or below, the minimum voltage remained within ANSI limits. Figure 19 and Figure 20 show the load profile and the maximum load for ANSI compliance (6.5 MVA). Note that load above 6.5 MVA is consistent for several days (17 days in July) as illustrated in Figure 19 and for several hours in a day (around 12 hours) as illustrated in Figure 20.

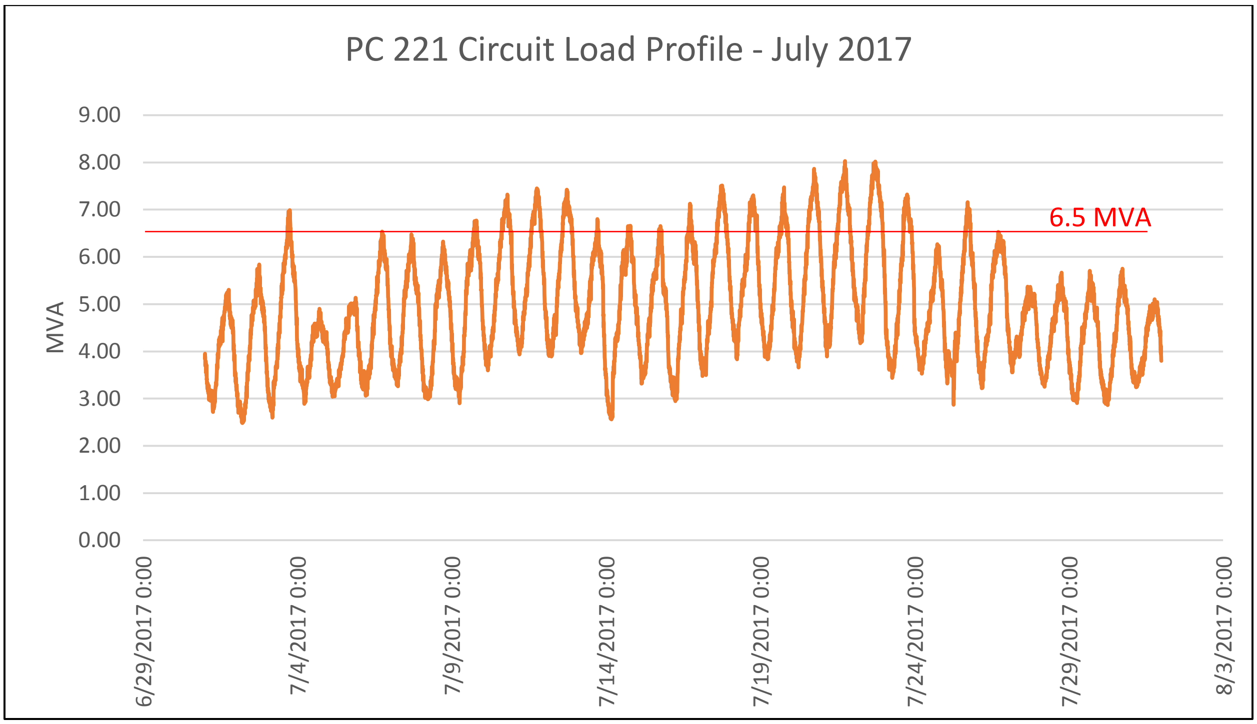


Figure 19. PC 221 load profile: July 2017.

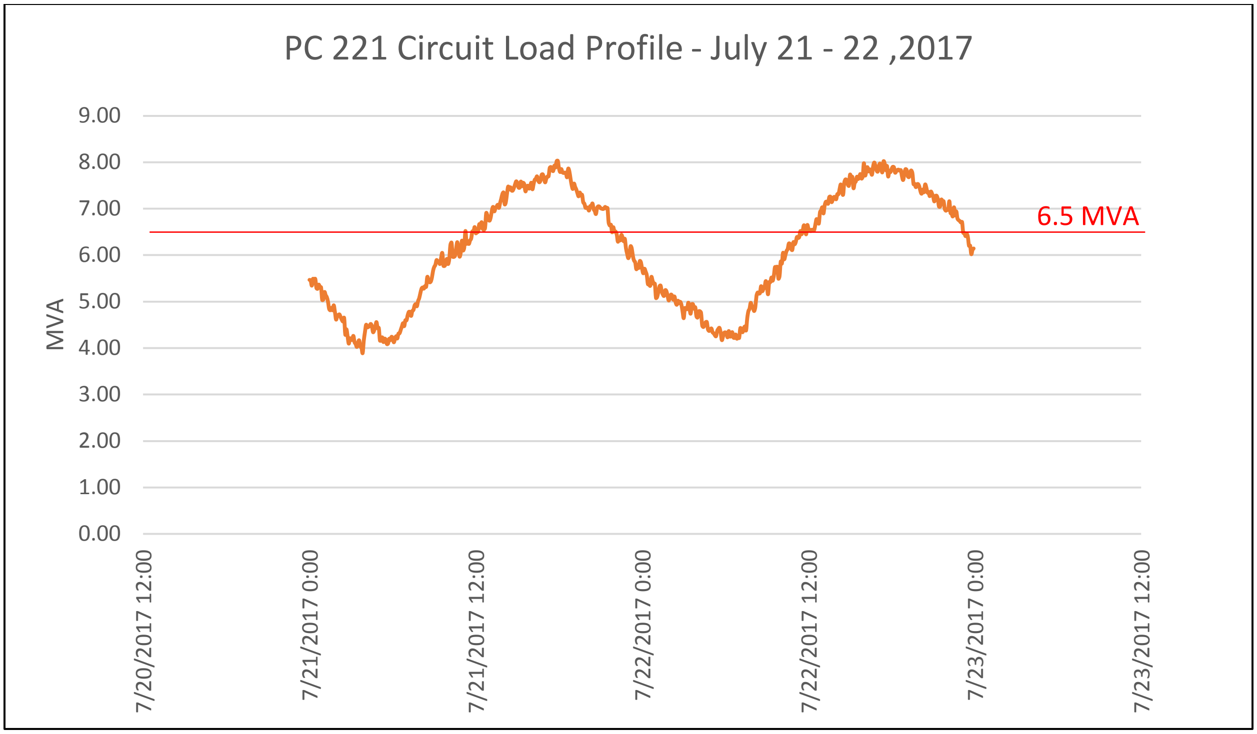


Figure 20. PC 221 circuit load profile: July 21–22, 2017.

According to the power flow simulation, circuit PC 221 violates voltage performance standards. This situation is expected to worsen as load on the feeder increases in the future. The CWLD is encouraged to assess mitigation measures to overcome the voltage issue. Some of the mitigation options could include the following:

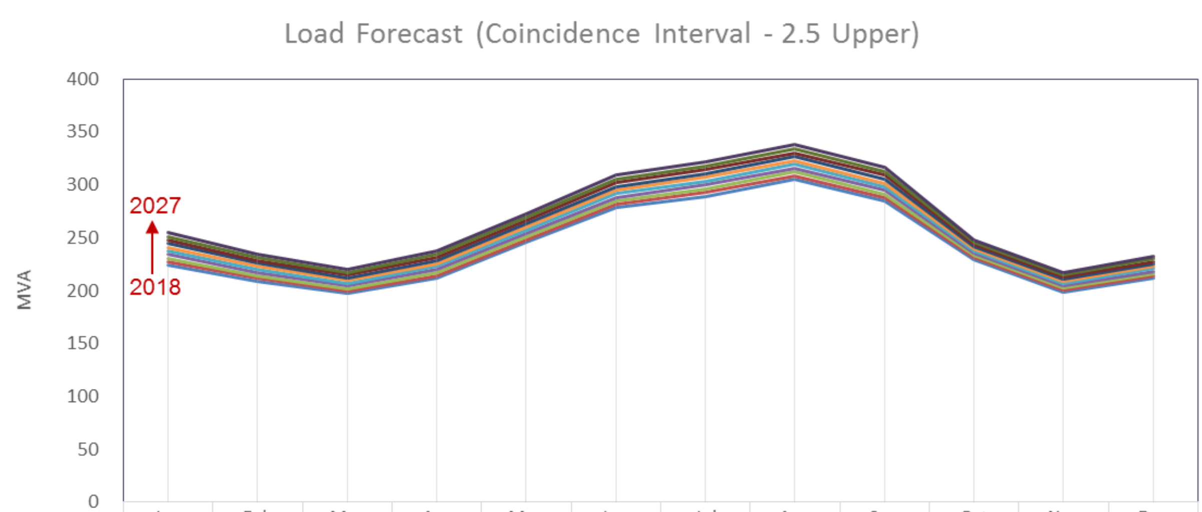
- Install a voltage regulator
- Add a new capacitor bank
- Load transfer to a neighboring circuit

These mitigation options are discussed in Section 6 of this report.

4 DISTRIBUTION SYSTEM PERFORMANCE - 5 YEARS

4.1 Load Growth

CWLD provided 14 years coincidental system peak demand forecast. See Figure 21 below. The peak demand shows a steady 1.1% demand growth year after year as shown in Table 19. The provided system demand forecast doesn't provide visibility of demand growth at substation level nor reflects demand growth geographically (e.g. City's Southwest area may be growing in a fast pace compared with downtown or Northeast areas).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	224	209	197	211	245	279	289	305	284	229	199	212
2019	227	212	199	214	248	282	293	309	288	231	201	214
2020	231	214	202	217	251	285	296	312	291	233	203	216
2021	234	217	204	220	254	288	300	316	295	235	205	218
2022	237	220	207	223	257	291	303	319	298	237	207	221
2023	241	223	209	226	260	295	307	323	302	239	209	223
2024	244	226	212	229	263	298	310	326	305	241	211	225
2025	248	229	215	232	266	302	314	330	309	244	213	228
2026	251	232	217	235	269	305	318	334	313	246	215	230
2027	255	235	220	238	272	309	322	338	316	248	217	232

MONTH / YEAR

Figure 21. System coincidental load forecast (2018 – 2027)

Table 19. Yearly peak load demand growth

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
1.11%	1.11%	1.11%	1.11%	1.11%	1.11%	1.11%	1.12%	1.12%	1.12%

To overcome the limited information regarding load forecast, the following approaches were implemented:

- At the substation level, a uniform non-coincidental forecast annual load growth of 2%, 3%, 4% and 5% was modeled as part of a growth sensitivity analysis
- At the distribution feeder level, a uniform non-coincident forecast load growth of 5.62% (yearly growth of 1.1% compounded in 5 years) were modeled as:
    - Organic growth (distributed along distribution circuit) applied to all distribution circuits
    - Spot load, equivalent to 5.62% of peak demand, located at the far end of three phase branch. This sensitivity analysis is applied to circuits at substation with potential overload conditions, namely GD, HC, and PC.

It is recommended that CWLD complete a spatial load forecast study at the substation level. Such a study will provide multiple benefits to system planning efforts, such as:

- Need for, siting of, and sizing of new HV/MV substations,
- Determining substation transformer capacity upgrade needs,
- Identify need for new distribution feeders in mid to long term planning
- Estimating load transfer capability among feeders and substations, create operating orders identifying switches to operate when a specific load transferring is required, and
- Provide inputs for an Integrated Resource Planning

4.2 Distribution Circuit Utilization Factor (UF) – 5.62% Load Growth

No overloads were observed at the feeder heads after applying the five year 5.62% compounded load growth (either organic growth or spot load) to each distribution circuit (See Figure 22 below). Feeder HC223 is the most heavily loaded feeder at 100% utilization factor.

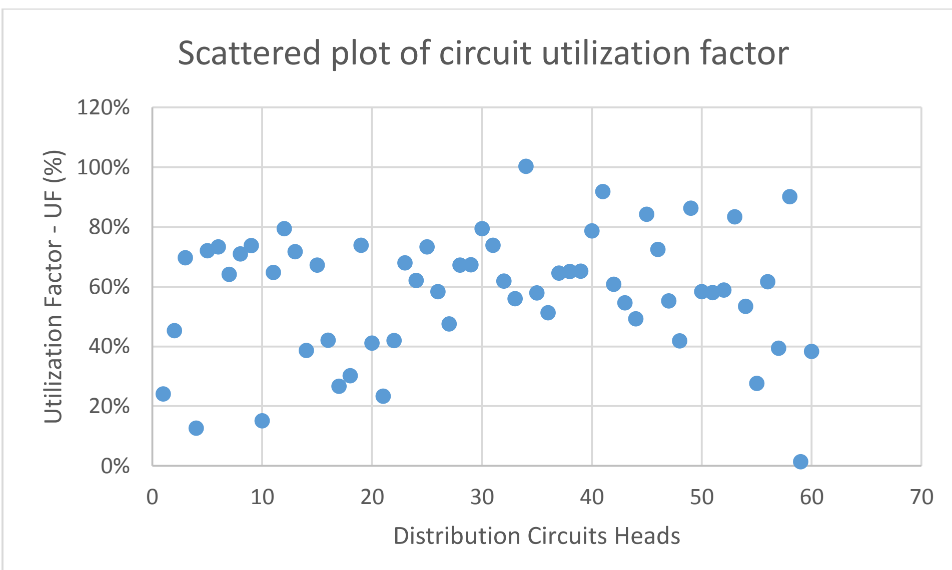


Figure 22. Scattered plot circuit utilization factor

Table 20 and Table 21 contain the calculated circuit capacity. There are no distribution circuit overload concerns. Blue bars, in Table 20 and Table 21, visually represents each distribution circuit utilization factor. Table 20 shows the circuit UF with calculated capacity for BD, BR, GD and HB circuits. Table 21 depicts the circuit UF with calculated capacity for HC, PC, PL and RH circuits.

Table 20. UF Comparison for BD, BR, GD and HB Circuits

Circuit	Calculated Capacity (MVA)	5.6% growth in 5 years 2022 MVA	UF - 2022 (%)
BD 211	9.51	2.29	24%
BD 212	9.51	4.31	45%
BD 213	9.51	6.63	70%
BD 221	9.51	1.20	13%
BD 222	9.51	6.86	72%
BD 223	9.51	6.98	73%
BR 211	9.80	6.29	64%
BR 212	9.80	6.96	71%
BR 213	9.80	7.23	74%
BR 221	9.80	1.48	15%
BR 222	9.80	6.34	65%
GD211	8.77	6.97	79%
GD212	8.77	6.30	72%
GD213	8.77	3.39	39%
GD221	8.77	5.90	67%
GD222	8.77	3.70	42%
GD223	8.77	2.34	27%
GD231	8.77	2.65	30%
GD232	8.77	6.48	74%
GD233	8.77	3.61	41%
HB 211	9.23	2.15	23%
HB 212	9.23	3.88	42%
HB 213	9.23	6.27	68%
HB 221	9.23	5.73	62%
HB 222	9.23	6.77	73%
HB 223	9.23	5.39	58%
HB 231	9.23	4.39	48%
HB 232	9.23	6.21	67%
HB 233	9.23	6.21	67%

Table 21. UF Comparison for HC, PC, PL and RH Circuits

	Calculated Capacity (MVA)	5.6% growth in 5 years	
Circuit		2022 MVA	UF - 2022 (%)
HC 211	9.18	7.29	79%
HC 212	9.18	6.78	74%
HC 213	9.18	5.69	62%
HC 221	9.18	5.14	56%
HC 223	9.18	9.21	100%
HC 231	9.18	5.32	58%
HC 232	9.18	4.71	51%
HC 233	9.18	5.92	65%
PC 211	9.23	6.01	65%
PC 212	9.23	6.02	65%
PC 213	9.23	7.26	79%
PC 221	9.23	8.48	92%
PC 222	9.23	5.61	61%
PC 223	9.23	5.04	55%
PL 212	8.92	4.39	49%
PL 213	8.92	7.51	84%
PL 214	8.92	6.47	73%
PL 221	8.92	4.93	55%
PL 222	8.92	3.73	42%
PL 223	8.92	7.70	86%
PL 231	8.92	5.21	58%
PL 232	8.92	5.17	58%
PL 233	8.92	5.26	59%
RH 211	9.42	7.86	83%
RH 212	9.42	5.03	53%
RH 213	9.42	2.61	28%
RH 214	9.42	5.81	62%
RH 221	9.42	3.71	39%
RH 222	9.42	8.49	90%
RH 223	9.42	0.13	1%
RH 224	9.42	3.61	38%

4.3 Distribution System Thermal Capacity – 5.62% Load Growth

For non-coincident circuit peak demand, two circuits were calculated to be loaded at 98% of capacity on a circuit section (circuit BD222 and PC211). These are the highest loading conditions on the system. In general, the CWLD's distribution system did not have any overloaded circuit sections. Figure 23 shows the calculated maximum thermal capacity ratio (loading capacity) of each of the analyzed 60 distribution circuit's sections. The "Y" axis represent the maximum thermal capacity expressed in % of each of the analyzed circuits. The "X" axis represents each of the 60 circuits

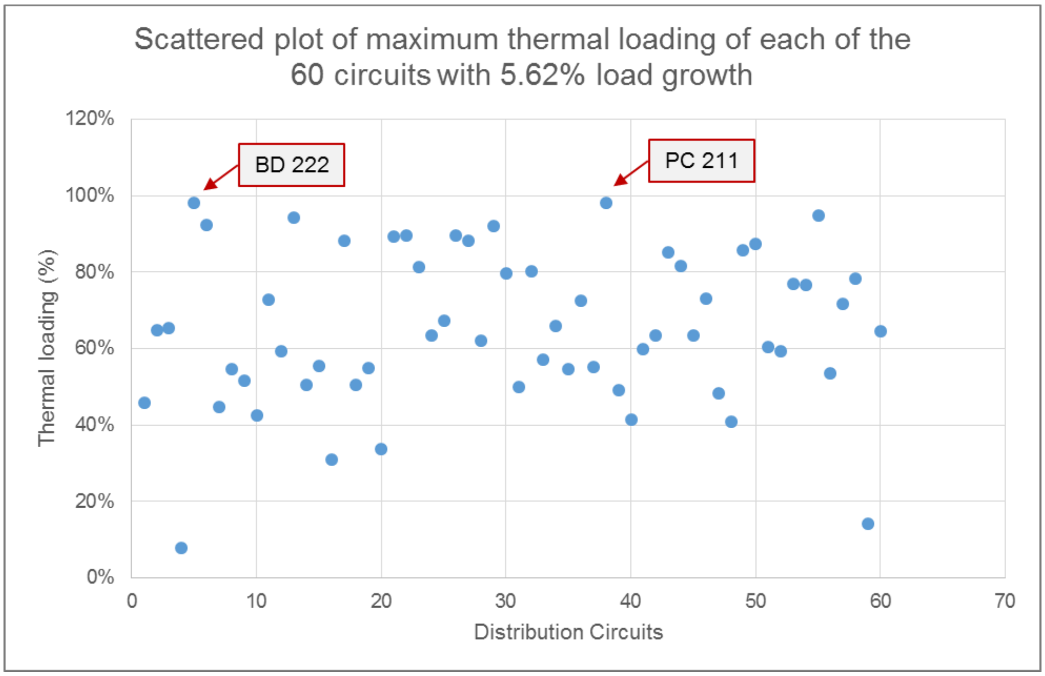


Figure 23. Distribution System, scattered plot maximum Thermal Loading of each circuit.

4.4 Distribution System Voltage Performance

In this analysis it is assumed a voltage regulator is installed on circuit PC 221 to address low voltages, as suggested in section 5.2.3, Installation of a 3-phase voltage regulator.

Organic load growth was analyzed first. Peak loads were increased by 5.62% on all feeders. All circuits comply with ANSI voltage standards. CWLD's design planning criteria considers a limited number of conductor and cable cross sections for main trunk lines. Such distribution planning criteria is very beneficial for voltage control and load transferring via distribution feeder ties, with minimum voltage concern. Load transferring will be discussed in section 5.1 Substation system Improvement – Current Conditions below.

The straight dotted red lines in Figure 24 show the maximum and minimum ANSI voltage levels (105% and 95% respectively). It also shows the maximum and minimum voltages from power flow modeling for

each distribution circuit. The maximum voltage levels are presented in dark-colored solid lines, while minimum voltage levels are presented in light-colored dotted lines. The "X" axis represents each of the 60 circuits. As observed, the minimum voltage is above 95% of nominal value.

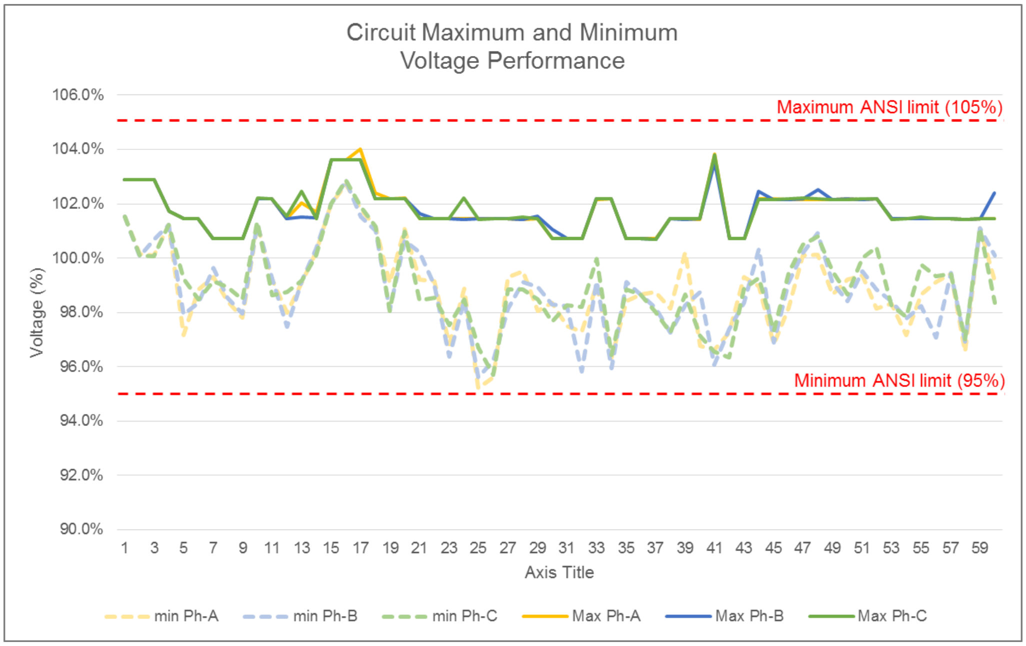


Figure 24. Maximum and minimum voltage of each distribution circuit.

Perche Creek, Harmony Branch, and Hinkson Creek substations are the most likely candidates for loading relief should the assumed forecast load growth occur in the areas supplied by these substation. Substation load growth sensitivity is discussed in section 5.1, Substation system Improvement – Current Conditions. Sensitivity analysis at distribution system level was performed for the following substation circuits:

- Grindstone (GD)
- Harmony Branch (HB)
- Hinkson Creek (HC)
- Perche Creek (PC)

Load growth to simulate extending feeders to pick up new loads was modeled by adding spot load, equivalent to 5.62% of peak demand, at the ends of three phase circuit sections.

Table 22 below shows the calculated spot load per circuit and power flow simulation results.

Table 22. Spot Load Allocation (5.62% of peak demand) and Power flow Simulation Results

Circuit	Spot load (KVA)	Minimum Voltage			Maximum Voltage			Max Loading (%)
		min Ph-A	min Ph-B	min Ph-C	Max Ph-A	Max Ph-B	Max Ph-C	
GD211	370.9	97.99%	97.49%	98.73%	101.45%	101.45%	101.52%	56%
GD212	335.1	99.22%	99.29%	99.31%	101.94%	101.49%	102.33%	89%
GD213	180.3	100.27%	100.39%	100.17%	101.69%	101.46%	101.45%	48%
GD221	314.1	102.04%	102.04%	102.04%	103.62%	103.62%	103.62%	52%
GD222	196.8	102.77%	102.88%	102.90%	103.62%	103.62%	103.62%	29%
GD223	124.6	101.88%	101.63%	101.94%	103.96%	103.62%	103.62%	84%
GD231	141	101.18%	101.06%	101.18%	102.37%	102.17%	102.17%	48%
GD232	345	99.26%	98.27%	98.22%	102.17%	102.17%	102.17%	46%
GD233	192.1	101.09%	100.68%	100.98%	102.21%	102.17%	102.17%	32%
HB 211	114.7	99.30%	100.27%	98.59%	101.45%	101.61%	101.45%	78%
HB 212	206.4	99.24%	99.11%	98.66%	101.45%	101.45%	101.45%	85%
HB 213	334	96.92%	96.51%	97.63%	101.45%	101.45%	101.45%	77%
HB 221	305.1	98.96%	98.60%	98.43%	101.45%	101.45%	102.14%	60%
HB 222	360.3	96.05%	95.45%	96.22%	101.45%	101.45%	101.45%	64%
HB 223	286.8	95.54%	96.35%	95.88%	101.45%	101.45%	101.45%	85%
HB 231	233.8	99.31%	98.22%	98.88%	101.45%	101.45%	101.45%	84%
HB 232	330.3	99.46%	99.12%	98.89%	101.45%	101.45%	101.49%	59%
HB 233	330.8	98.20%	99.02%	98.62%	101.45%	101.52%	101.45%	92%
HC 211	388.2	98.43%	98.41%	97.77%	100.72%	100.97%	100.72%	76%
HC 212	360.9	97.54%	98.23%	98.28%	100.72%	100.72%	100.72%	50%
HC 213	302.7	97.43%	96.00%	98.27%	100.72%	100.72%	100.72%	76%
HC 221	273.7	99.19%	99.32%	100.06%	102.17%	102.17%	102.17%	60%
HC 223	490.3	96.23%	95.87%	96.32%	102.17%	102.17%	102.17%	66%
HC 231	283.3	98.49%	99.14%	98.89%	100.72%	100.72%	100.72%	52%
HC 232	250.5	98.76%	98.76%	98.76%	100.72%	100.72%	100.72%	69%
HC 233	315.3	98.82%	98.28%	98.13%	100.72%	100.72%	100.72%	52%
PC 211	319.7	98.28%	97.40%	97.43%	101.45%	101.45%	101.45%	98%
PC 212	320.3	100.28%	98.33%	98.71%	101.45%	101.45%	101.45%	49%
PC 213	386.4	96.92%	98.77%	97.14%	101.45%	101.45%	101.45%	39%
PC 221	451.4	96.69%	96.17%	96.58%	103.79%	103.79%	103.53%	60%
PC 222	298.6	97.39%	97.48%	96.51%	100.72%	100.72%	100.72%	60%
PC 223	268.2	99.32%	98.41%	98.89%	100.72%	100.72%	100.72%	86%

No voltage or thermal violations were identified when adding spot loads to the circuits (see below). No system reinforcements are required to accommodate up to 5.62% load growth. It is however recommended to revise the assumed load growth based on any future load forecast studies.

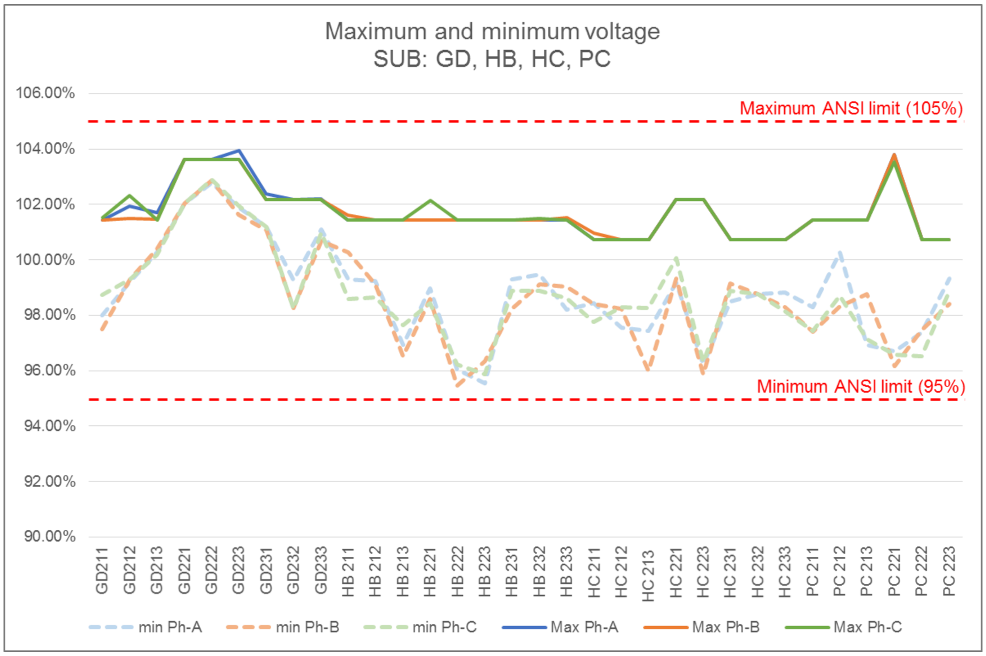


Figure 25. Maximum and minimum voltage, GD, HB, HC and PC circuits

4.5 Load transfer Capability via Distribution Circuits

The load transfer capability study discussed in this section was performed with the goal of evaluating load transfers between substations via distribution circuit ties. The study identifies the maximum amount of kVA that can safely be transferred off of a substation transformer via existing distribution circuit ties. The maximum load transfer capability is limited by the circuit voltage performance or the maximum rated circuit capacity of 372 Amps in accordance by the CWLD's standard practice. This load transfer capability does not consider substation transformation capacity. Substation transformation capacity is studied in section 5.1 Substation system Improvement – Current Conditions. The study also considers 1.1% load growth from 2017 to 2018 and that the existing switches have load break capability.

CWLD has installed a good number of switches throughout the distribution system which enable load transfers between circuits and substations. This study will focus on the maximum amount of load that can be transferred so as to relieve substation transformer overloads.

Table 23 and

From		To SUB (KVA)								Total (KVA)
SUB	Circuit	DB	BR	GD	HB	HC	PC	PL	RH	
BR	BR 211	-	-	-	-	-	-	3,861	-	3,861
BR	BR 212	-	-	-	2,412	-	-	3,603	-	6,015
BR	BR 213	2,211	-	-	-	-	-	-	15,065	17,276
BR	BR 221	1,388	-	-	-	-	-	-	-	1,388
BR	BR 222	-	-	-	-	-	-	5,321	-	5,321
BD	BD 211	-	-	-	-	-	-	-	-	-
BD	BD 212	-	4,060	-	-	-	-	-	-	4,060
BD	BD 213	-	-	-	-	-	-	-	1,702	1,702
BD	BD 221	-	-	-	-	-	-	-	-	-
BD	BD 222	-	-	-	-	-	-	-	-	-
BD	BD 223	-	1,971	-	-	-	-	-	-	1,971
GD	GD211	-	-	-	-	1,911	-	-	-	1,911
GD	GD212	-	-	-	-	-	-	-	1,368	1,368
GD	GD213	-	-	-	-	-	-	-	-	-
GD	GD221	-	-	-	-	-	-	-	-	-
GD	GD222	-	-	-	-	-	-	-	1,368	1,368
GD	GD223	-	-	-	-	-	-	-	1,368	1,368
GD	GD231	-	-	-	-	-	-	-	-	-
GD	GD232	-	-	-	-	4,387	-	2,997	2,997	10,381
GD	GD233	-	-	-	-	3,384	-	-	-	3,384
HB	HB 211	-	-	-	-	-	-	-	-	-
HB	HB 212	-	-	-	-	-	-	-	-	-
HB	HB 213	-	-	-	-	-	-	-	-	-
HB	HB 221	-	-	-	-	-	2,448	-	-	2,448
HB	HB 222	-	2,234	-	-	-	-	4,685	-	6,919
HB	HB 223	-	-	-	4,688	7,191	3,269	1,702	-	16,850
HB	HB 231	-	-	-	3,734	-	-	-	-	3,734
HB	HB 232	-	-	-	-	-	7,756	-	-	7,756
HB	HB 233	-	-	-	-	-	-	-	-	-
HC	HC 211	-	-	2,221	-	-	-	-	-	2,221
HC	HC 212	-	-	-	-	-	-	-	-	-
HC	HC 213	-	-	-	-	-	1,943	-	-	1,943
HC	HC 221	-	-	-	3,734	-	2,667	-	-	6,401
HC	HC 222	-	-	-	-	-	-	-	-	-
HC	HC 223	-	-	-	-	-	1,943	-	-	1,943
HC	HC 231	-	-	5,017	-	-	-	-	-	5,017
HC	HC 232	-	-	-	-	-	-	-	-	-
HC	HC 233	-	-	-	3,000	-	-	4,404	-	7,404

Table 24 show the maximum amount of load that can be transferred from each of the substation transformers under 2018 peak conditions. Appendix E shows the maximum load that can be transferred from each distribution circuit.

Table 23. Maximum Transfer Capability from Circuit to Substation through Distribution Circuit ties

From		To SUB (KVA)								Total (KVA)
SUB	Circuit	DB	BR	GD	HB	HC	PC	PL	RH	
BR	BR 211	-	-	-	-	-	-	3,861	-	3,861
BR	BR 212	-	-	-	2,412	-	-	3,603	-	6,015
BR	BR 213	2,211	-	-	-	-	-	-	15,065	17,276
BR	BR 221	1,388	-	-	-	-	-	-	-	1,388
BR	BR 222	-	-	-	-	-	-	5,321	-	5,321
BD	BD 211	-	-	-	-	-	-	-	-	-
BD	BD 212	-	4,060	-	-	-	-	-	-	4,060
BD	BD 213	-	-	-	-	-	-	-	1,702	1,702
BD	BD 221	-	-	-	-	-	-	-	-	-
BD	BD 222	-	-	-	-	-	-	-	-	-
BD	BD 223	-	1,971	-	-	-	-	-	-	1,971
GD	GD211	-	-	-	-	1,911	-	-	-	1,911
GD	GD212	-	-	-	-	-	-	-	1,368	1,368
GD	GD213	-	-	-	-	-	-	-	-	-
GD	GD221	-	-	-	-	-	-	-	-	-
GD	GD222	-	-	-	-	-	-	-	1,368	1,368
GD	GD223	-	-	-	-	-	-	-	1,368	1,368
GD	GD231	-	-	-	-	-	-	-	-	-
GD	GD232	-	-	-	-	4,387	-	2,997	2,997	10,381
GD	GD233	-	-	-	-	3,384	-	-	-	3,384
HB	HB 211	-	-	-	-	-	-	-	-	-
HB	HB 212	-	-	-	-	-	-	-	-	-
HB	HB 213	-	-	-	-	-	-	-	-	-
HB	HB 221	-	-	-	-	-	2,448	-	-	2,448
HB	HB 222	-	2,234	-	-	-	-	4,685	-	6,919
HB	HB 223	-	-	-	4,688	7,191	3,269	1,702	-	16,850
HB	HB 231	-	-	-	3,734	-	-	-	-	3,734
HB	HB 232	-	-	-	-	-	7,756	-	-	7,756
HB	HB 233	-	-	-	-	-	-	-	-	-
HC	HC 211	-	-	2,221	-	-	-	-	-	2,221
HC	HC 212	-	-	-	-	-	-	-	-	-
HC	HC 213	-	-	-	-	-	1,943	-	-	1,943
HC	HC 221	-	-	-	3,734	-	2,667	-	-	6,401
HC	HC 222	-	-	-	-	-	-	-	-	-
HC	HC 223	-	-	-	-	-	1,943	-	-	1,943
HC	HC 231	-	-	5,017	-	-	-	-	-	5,017
HC	HC 232	-	-	-	-	-	-	-	-	-
HC	HC 233	-	-	-	3,000	-	-	4,404	-	7,404

Table 24. Maximum Transfer Capability from Circuit to Substation through Distribution Circuit ties

From		To SUB (KVA)								Total (KVA)
SUB	Circuit	DB	BR	GD	HB	HC	PC	PL	RH	
PC	PC 211	-	-	-	2,952	-	-	-	-	2,952
PC	PC 212	-	-	-	6,686	-	-	-	-	6,686
PC	PC 213	-	-	-	4,952	5,023	-	-	-	9,975
PC	PC 221	-	-	-	-	-	-	-	-	-
PC	PC 222	-	-	-	3,340	-	-	-	-	3,340
PC	PC 223	-	-	-	-	-	-	-	-	-
PL	PL 212	-	-	-	2,412	-	-	-	-	2,412
PL	PL 213	-	-	-	3,734	2,078	-	-	-	5,812
PL	PL 214	-	-	-	-	3,222	-	-	-	3,222
PL	PL 221	-	-	-	-	-	-	-	-	-
PL	PL 222	-	2,818	-	-	-	-	-	764	3,583
PL	PL 223	-	-	-	-	-	-	-	-	-
PL	PL 231	-	-	2,688	-	-	-	-	4,075	6,763
PL	PL 232	-	-	-	-	-	-	-	-	-
PL	PL 233	-	5,107	-	-	-	-	-	-	5,107
RH	RH 211	-	-	10,933	-	-	-	-	-	10,933
RH	RH 212	-	-	2,688	-	-	-	3,907	-	6,595
RH	RH 213	-	1,971	-	-	-	-	-	-	1,971
RH	RH 214	2,360	1,052	-	-	-	-	-	-	3,412
RH	RH 221	-	1,971	-	-	-	-	-	-	1,971
RH	RH 222	-	-	-	-	-	-	5,321	-	5,321
RH	RH 223	-	-	-	-	-	-	-	-	-
RH	RH 224	-	-	-	-	-	-	-	-	-

5 SYSTEM IMPROVEMENT

5.1 Substation system Improvement – Current Conditions

A substation by substation capacity adequacy assessment was performed to determine the ability to serve substation loads under first contingency (N-1) transformer outage conditions. The analysis started with the individual loads forecast for each substation and included the planned, permanent, transfer of 4 MVA of load from Perche Creek transformers 1 and 2 to Harmony Branch transformers 1 and 2. Harmony Branch transformer #3 was treated as a standalone, single unit, station since there is no bus tie between buses 2 and 3.

The adequacy assessment considered the N-1 transformer capacity of a station and the aggregate substation load assuming that any available bus tie breakers would be closed to serve the load. In the case of the Power Plant Substation, it was assumed that local generation would be used to reduce post contingency loading. Load transfers between substations by way of feeder to feeder transfers were considered in the event that the aggregate substation load exceeded the N-1 transformer capacity. The maximum amount of load that could be shifted between substations by feeder to feeder transfers was determined based on:

1. Thermal capacity of the receiving feeder assuming CWLD's standard rating of 372 Amp
2. Maintaining acceptable feeder voltages
3. Limiting the post transfer loading on the receiving transformer to its 65^{o}C nameplate rating.
4. Bus tie breakers in the substations to which loads are transfered are assumed to remain open. Additional load transfers might be possible by closing these bus tie breakers but this would expose load to breaker failure events.
5. MW load loss after considering feeder to feeder transfers is calculated based on load in excess of the substations N-1 transformer capacity based on 65^{o}C nameplate rating. The load in excess of 65^{o}C nameplate rating is also represented as a percentage of this rating for comparison with the assumed generic example of 2% loss of life rating, 125% of nameplate. The need for substation capacity additions can be measured against risk tolerance for a planned loss of load or transformer loss of life.

The adequacy assessment included the 2018 individual peak substation load forecast and a range of individual, non-coincident substation load forecasts. Absent substation specific load forecast data the study assumed uniform non-coincident load forecasts at each substation.

The adequacy assessment assumed non-coincident peak substation load forecasts. It is typical that individual substations will peak at different hours, and occasionally on different days or in different weeks, than when the aggregate system peak occurs. Contributing to this is the composition of the loads, residential, commercial, and industrial, at the individual substations. Similarly, it is common for the forecast load growth at individual substations to vary from that of the aggregate system. Based on localized conditions individual substations may have a growth rate 2-5 times that of the aggregate system. Some substations may exhibit negative growth while the aggregate system and neighboring substations have positive growth. Individual substation adequacy needs to be planned to meet each substations non-coincident load and load forecast rather than the coincident loads forecast at the time of the aggregate system peak.

Absent individual substation load forecast data, uniform non-coincident forecast load growth of 2%, 3%, 4%, and 5% were modeled as part of a load growth sensitivity analysis. Should the forecast load exceed a station's N-1 transformer capacity, load was assumed to be transferred to adjacent substations based on the feeder to feeder evaluations. Feeder to feeder transfers were limited by the receiving transformer's available capacity including that substation's assumed forecast growth. The analysis of individual substations can be refined by substituting more case specific load growth forecasts for both the substation being evaluated and those to which loads would be transferred.

The following tables assess individual substation capacity adequacy based on a 2018 peak forecast and then five and ten years of compound growth based on the assumed uniform growth rates. Included in the tables are the substation nameplate transformer capacity, the N-1 substation capacity assuming that available 13.8kV bus tie breakers are closed, the forecast load by year, the sum of loads which could be transferred to adjacent substations adjusted to reflect adjacent substation load growth, the amount of load that exceeds the N-1 substation capacity plus available load transfer, and the percent overload of the 65^{o}C nameplate rating of the N-1 transformer capacity. This latter value would be used should CWLD develop and implement an acceptable loss of life rating based on transformer nameplate data and an acceptable top oil temperature. This value represents the amount of load that would need to be curtailed if the rating is capped at the 65^{o}C nameplate rating.

Based on the load forecast and feeder to feeder transfer assumptions of this assessment, the adequacy calculations suggest that the individual substations have adequate capacity to support load growth of up to 5% per year for 5-years. The exceptions to this are Harmony Branch #3 and Perche Creek. Harmony Branch #3, in the absence of a bus tie, will require additional feeder to feeder transfer capability to address a transformer outage. In discussions with the City it was indicated that there were plans for expansion of this capability. The Perche Creek Substation would be exposed to a 2 MVA overload in year 5 if it and its adjacent substations all saw 5% growth over five years.

Using a 3% non-coincident load growth as a proxy for strong localized load growth, there is adequate N-1 substation capacity in the first five years of the analysis. However, extending this assessment out to 10 years, as a proxy for more active local development and related local load growth, provides an indication of which substations may be the first to experience a future capacity shortfall. Subject to more rigorous local load forecasting data and detailed feeder load carrying capability, the areas supplied by Perche Creek, Harmony Branch, and Hinkson Creek Substations may be candidates for substation capacity additions should they experience a significant step change or year on year load growth.

Two things of note; first, this test of substation adequacy is a function of the load growth at the substation in question as well as adjacent substations. The ability to accept load transfers is diminished over time as the loads on the adjacent transformers increase. Therefore the adequacy of a substation becomes a function of its forecast load growth as well as that of adjacent substations. Second, the 10 year assessment is included for illustrative purposes only. It is not likely that individual substations would experience a sustained non-coincident compound growth rate in multiples of the aggregate system forecast over a ten year period. However, the ten year adequacy metrics do provide some insights as to which substations should be monitored should concentrated load growth occur.

The adequacy assessment assumes that the CWLD puts in place procedures to facilitate feeder to feeder load transfers in order to quickly mitigate potential transformer overloads should a transformer failure occur. The risk of overloading a transformer prior to transferring loads is reduced by the probability of

the transformer outage occurring at or near peak conditions and the time delay between a step change in the transformer loading and the increase in the top oil temperature. In any event, it would be good practice to identify the feeder to feeder transfers associated with substations exposed to N-1 overloads and insure that the switching actions can be implemented in a timely manner.

Table 25 Forecast Substation Adequacy: 2% Growth

					2018					5 years					10 years				
	Nameplate	N-1 Nameplate	2% LoL 125% N-1 Nameplate	Est Annual Load Growth	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload
Blue Ridge	44.8	22.4	28	2.0%	24.1	1.7	32.8			26.6	4.2	30.1			29.4	7.0	26.1		
Bolstad	44.8	22.4	28	2.0%	18.8	0	7.7			20.8	0.0	7.7			22.9	0.5	7.7		
Grindstone	67.2	44.8	56	2.0%	36.5	0	19.8			40.3	0.0	18.4			44.5	0.0	13.3		
Harmony 1-2	44.8	22.4	28	2.0%	31.4	9	26.2			34.7	12.3	26.2			38.3	15.9	23.5		
Harmony 3	22.4	0	0	2.0%	15.2	15.2	6.3	8.9	N/A	16.8	16.8	4.6	12.2	N/A	18.5	18.5	1.9	16.6	N/A
Hinkson	67.2	44.8	56	2.0%	45.1	0.3	24.3			49.8	5.0	21.0			55.0	10.2	17.3		
Perche	44.8	22.4	28	2.0%	31.9	9.5	21.8			35.2	12.8	20.2			38.9	16.5	16.1	0.4	102%
Power Plant	67.2	44.8	56	2.0%	42.3	0	26.9			46.7	1.9	24.2			51.6	6.8	20.4		
Rebel	56	28	35	2.0%	33.4	5.4	30.2			36.9	8.9	29.1			40.7	12.7	27.0		

Table 26 Forecast Substation Adequacy: 3% Growth

					2018					5 years					10 years				
	Nameplate	N-1 Nameplate	2% LoL 125% N-1 Nameplate	Est Annual Load Growth	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload
Blue Ridge	44.8	22.4	28	3.0%	24.1	1.7	32.8			27.9	5.5	28.2			32.4	10.0	18.7		
Bolstad	44.8	22.4	28	3.0%	18.8	0	7.7			21.8	0.0	7.7			25.3	2.9	5.8		
Grindstone	67.2	44.8	56	3.0%	36.5	0	19.8			42.3	0.0	16.3			49.1	4.3	8.5		
Harmony 1-2	44.8	22.4	28	3.0%	31.4	9	26.2			36.4	14.0	26.0			42.2	19.8	14.7	5.1	123%
Harmony 3	22.4	0	0	3.0%	15.2	15.2	6.3	8.9	N/A	17.6	17.6	3.7	13.9	N/A	20.4	20.4	0.0	20.4	N/A
Hinkson	67.2	44.8	56	3.0%	45.1	0.3	24.3			52.3	7.5	19.2			60.6	15.8	12.4	3.4	108%
Perche	44.8	22.4	28	3.0%	31.9	9.5	21.8			37.0	14.6	18.5			42.9	20.5	11.6	8.8	139%
Power Plant	67.2	44.8	56	3.0%	42.3	0	26.9			49.0	4.2	22.4			56.8	12.0	12.7		
Rebel	56	28	35	3.0%	33.4	5.4	30.2			38.7	10.7	28.1			44.9	16.9	22.0		

Table 27 Forecast Substation Adequacy: 4% Growth

					2018					5 years					10 years				
	Nameplate	N-1 Nameplate	2% LoL 125% N-1 Nameplate	Est Annual Load Growth	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload
Blue Ridge	44.8	22.4	28	4.0%	24.1	1.7	32.8			29.3	6.9	26.2			35.7	13.3	11.8	1.4	106%
Bolstad	44.8	22.4	28	4.0%	18.8	0	7.7			22.9	0.5	7.7			27.8	5.4	4.1	1.4	106%
Grindstone	67.2	44.8	56	4.0%	36.5	0	19.8			44.4	0.0	13.4			54.0	9.2	2.9	6.3	114%
Harmony 1-2	44.8	22.4	28	4.0%	31.4	9	26.2			38.2	15.8	23.7			46.5	24.1	6.2	17.9	180%
Harmony 3	22.4	0	0	4.0%	15.2	15.2	6.3	8.9	N/A	18.5	18.5	2.0	16.5	N/A	22.5	22.5	0.0	22.5	N/A
Hinkson	67.2	44.8	56	4.0%	45.1	0.3	24.3			54.9	10.1	17.4			66.8	22.0	6.7	15.2	134%
Perche	44.8	22.4	28	4.0%	31.9	9.5	21.8			38.8	16.4	16.2	0.2	101%	47.2	24.8	8.8	16.1	172%
Power Plant	67.2	44.8	56	4.0%	42.3	0	26.9			51.5	6.7	20.5			62.6	17.8	7.8	10.0	122%
Rebel	56	28	35	4.0%	33.4	5.4	30.2			40.6	12.6	27.1			49.4	21.4	15.3	6.1	122%

Table 28 Forecast Substation Adequacy: 5% Growth

					2018					5 years					10 years				
	Nameplate	N-1 Nameplate	2% LoL 125% N-1 Nameplate	Est Annual Load Growth	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload	Load	N-1 Overload	Max Load Transfer Away	Load Loss or Overload	% N-1 Overload
Blue Ridge	44.8	22.4	28	5.0%	24.1	1.7	32.8			30.8	8.4	23.0			39.3	16.9	8.6	8.2	137%
Bolstad	44.8	22.4	28	5.0%	18.8	0	7.7			24.0	1.6	6.7			30.6	8.2	4.1	4.2	119%
Grindstone	67.2	44.8	56	5.0%	36.5	0	19.8			46.6	1.8	10.8			59.5	14.7	0.0	14.7	133%
Harmony 1-2	44.8	22.4	28	5.0%	31.4	9	26.2			40.1	17.7	19.8			51.1	28.7	1.1	27.7	224%
Harmony 3	22.4	0	0	5.0%	15.2	15.2	6.3	8.9	N/A	19.4	19.4	0.1	19.3	N/A	24.8	24.8	0.0	24.8	N/A
Hinkson	67.2	44.8	56	5.0%	45.1	0.3	24.3			57.6	12.8	15.5			73.5	28.7	4.2	24.5	155%
Perche	44.8	22.4	28	5.0%	31.9	9.5	21.8			40.7	18.3	13.7	4.6	120%	52.0	29.6	7.3	22.3	199%
Power Plant	67.2	44.8	56	5.0%	42.3	0	26.9			54.0	9.2	17.0			68.9	24.1	6.3	17.8	140%
Rebel	56	28	35	5.0%	33.4	5.4	30.2			42.6	14.6	25.3			54.4	26.4	10.8	15.6	156%

5.2 Distribution System Improvements – Current Conditions

To solve the circuit PC 221 low voltage issue the following options were evaluated.

5.2.1 Add a new capacitor bank.

Currently, the PC 221 circuit power factor is 99%, leaving no room for additional reactive compensation. Therefore, this option is not applicable.

5.2.2 Load balancing and relocating existing 900 kVAR capacitor bank

Around 40 kVA of load was transfered from B to A phase, and 40 kVA of load was transfered from B to C phase. The minimum voltage improved from 112.4 to 112.5 V, as shown in Figure 26. The existing capacitor banks were relocated upstream. With all changes, the voltage profile was not improved. This option is not viable.

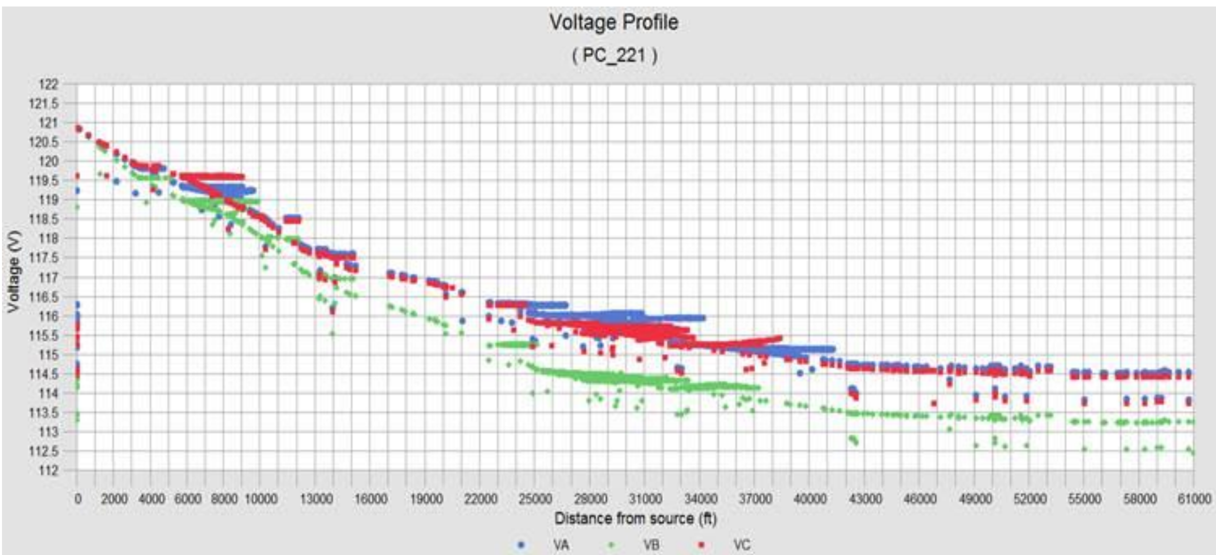


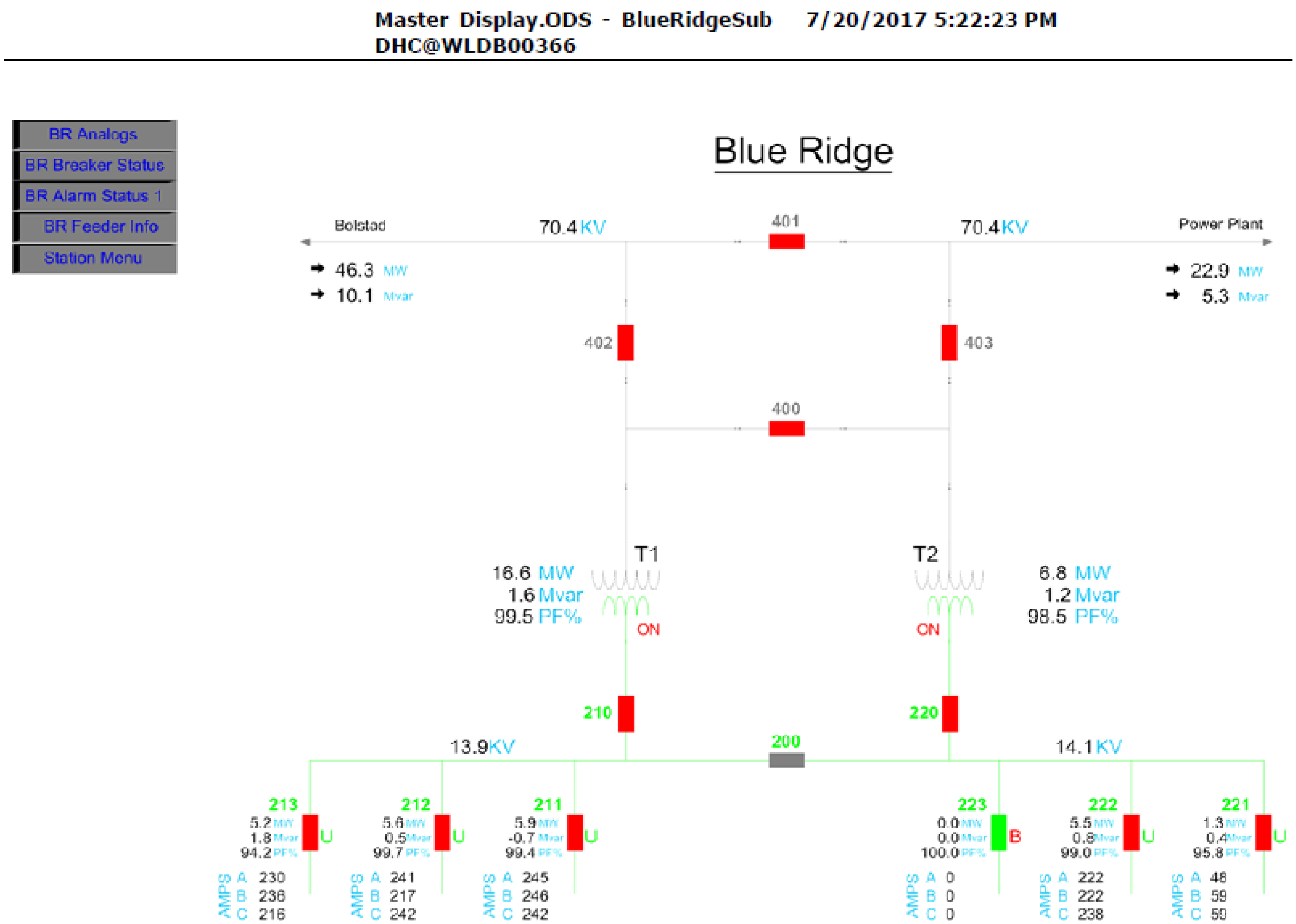
Figure 26. Voltage profile after load balancing and relocating existing 900 kVAR capacitor bank.

5.2.3 Installation of a 3-phase voltage regulator.

A new 3-phase 200-amp voltage regulator is added at around 20,000 feet downstream of the PC substation. The voltage profile improved as shown in the voltage profile below (see Figure 27). The minimum registered voltage is 96.28% (115.5 V) in phase B. This corrected the low voltage condition. It is recommended to add a voltage regulator as a short term solution.

Figure 27. Voltage Profile after Installing a Voltage Regulator

APPENDIX A: SUBSTATION SINGLE LINE DIAGRAM



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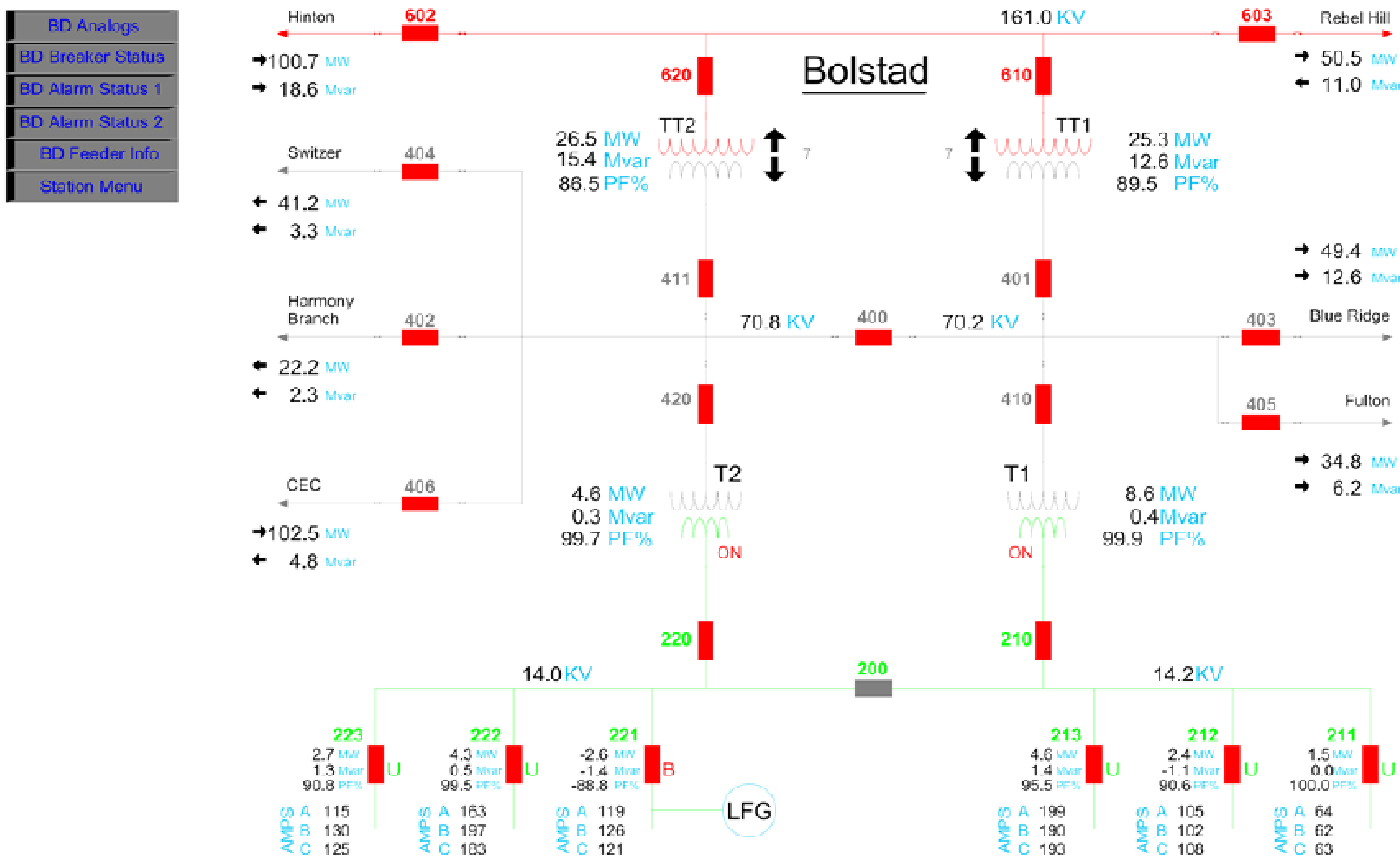
DHC@WLDB00366



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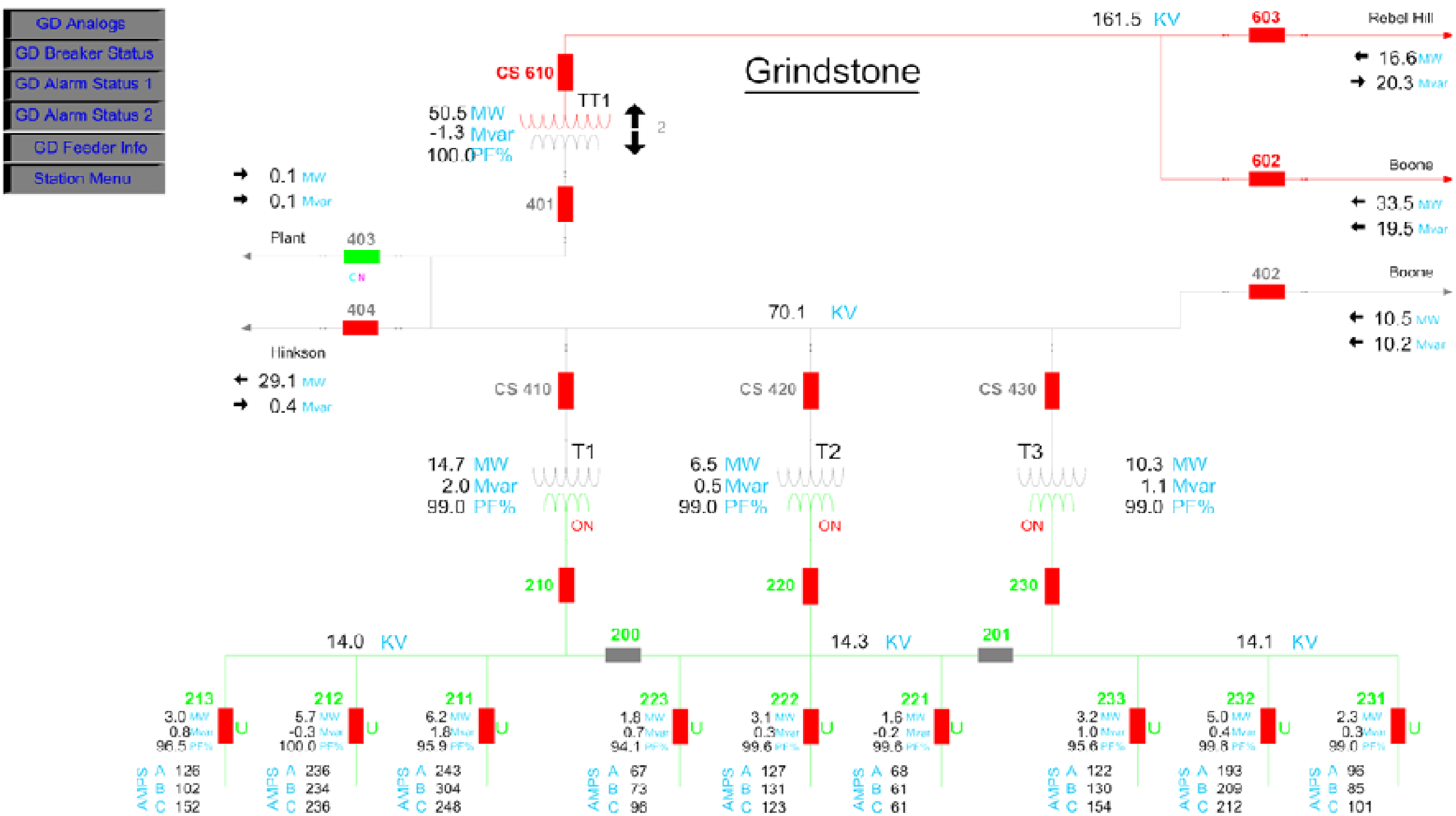
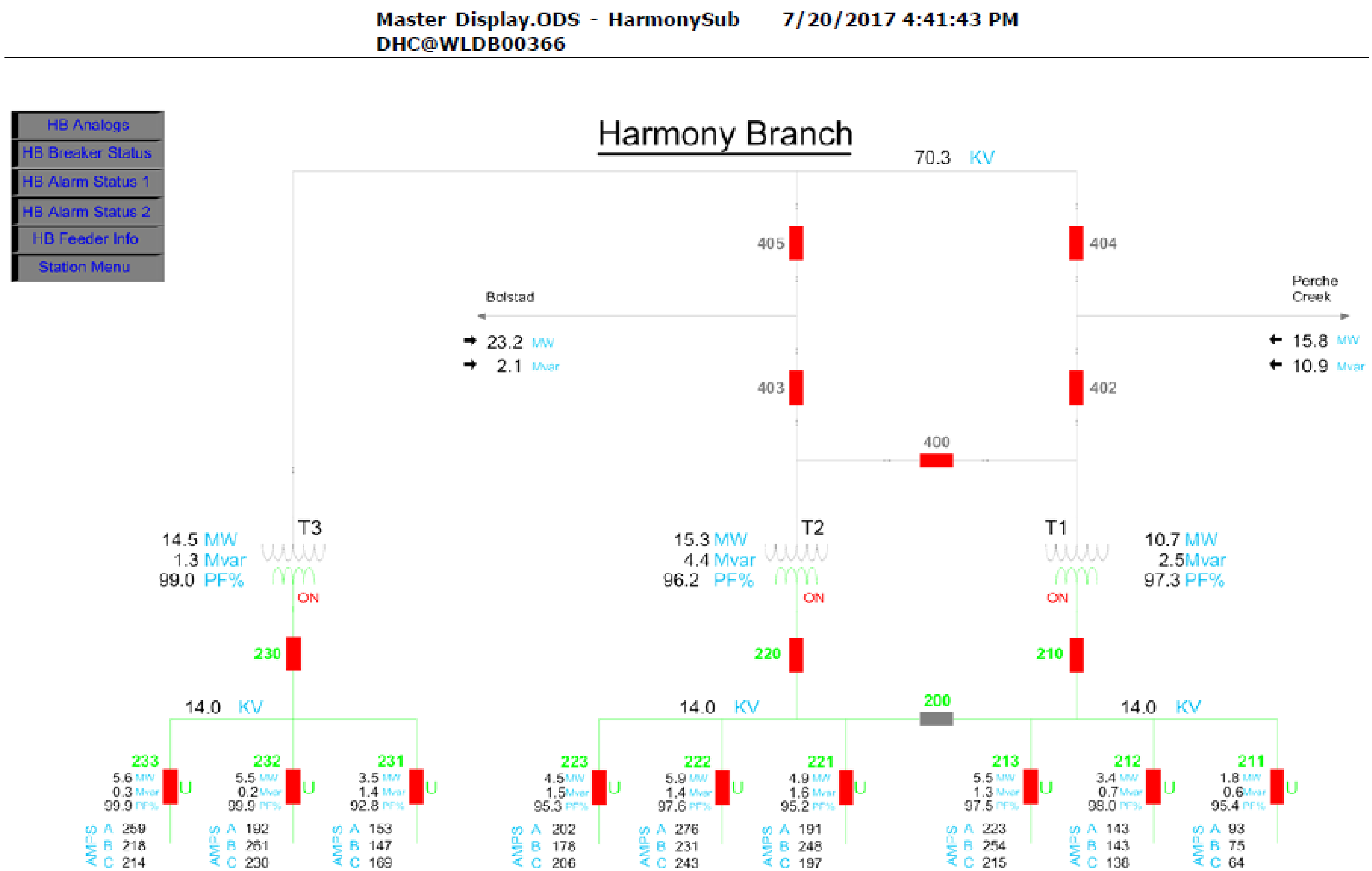
DHC@WLDB00366

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DHC@WLDB00366
HB Analogs
HB Breaker Status
HB Alarm Status 1
HB Alarm Status 2
HB Feeder Info
Station Menu
Harmony Branch
70.3 KV
405
404
Bolstad
Perche Creek
23.2 MW
2.1 Mvar
15.8 MW
10.9 Mvar
403
402
400
T3
T2
T1
14.5 MW
1.3 Mvar
99.0 PF%
15.3 MW
4.4 Mvar
96.2 PF%
10.7 MW
2.5Mvar
97.3 PF%
ON
230
220
210
200
14.0 KV
233
5.6 MW
0.3 Mvar
99.9 PF%
AMPS A 259 B 218 C 214
232
5.5 MW
0.2 Mvar
99.9 PF%
AMPS A 192 B 261 C 230
231
3.5 MW
1.4 Mvar
92.8 PF%
AMPS A 153 B 147 C 169
223
4.5 MW
1.5 Mvar
95.3 PF%
AMPS A 202 B 178 C 206
222
5.9 MW
1.4 Mvar
97.6 PF%
AMPS A 276 B 231 C 243
221
4.9 MW
1.6 Mvar
95.2 PF%
AMPS A 191 B 248 C 197
213
5.5 MW
1.3 Mvar
97.5 PF%
AMPS A 223 B 254 C 215
212
3.4 MW
0.7 Mvar
98.0 PF%
AMPS A 143 B 143 C 136
211
1.8 MW
0.6 Mvar
95.4 PF%
AMPS A 93 B 75 C 64

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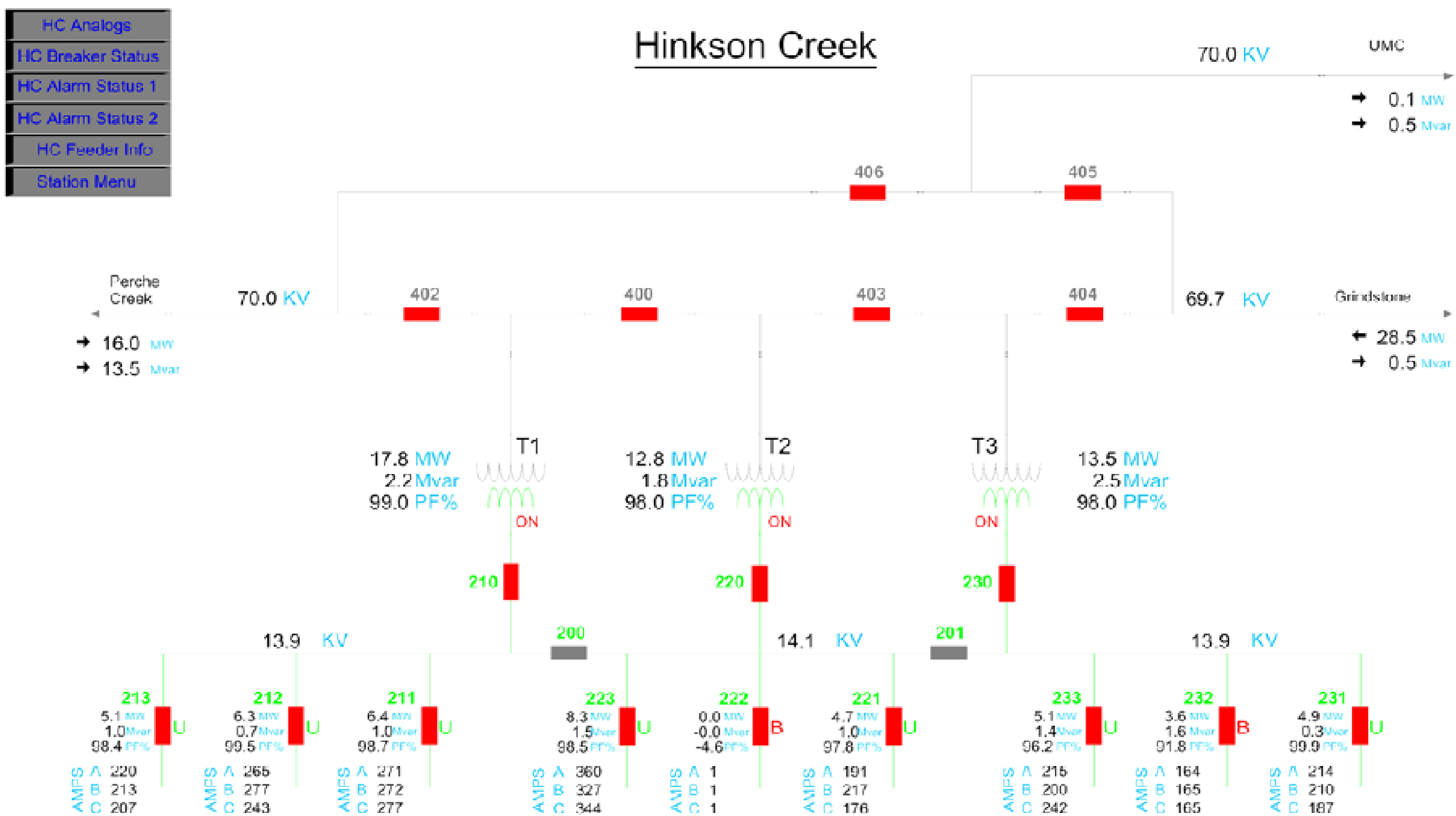
DHC@WLDB00366



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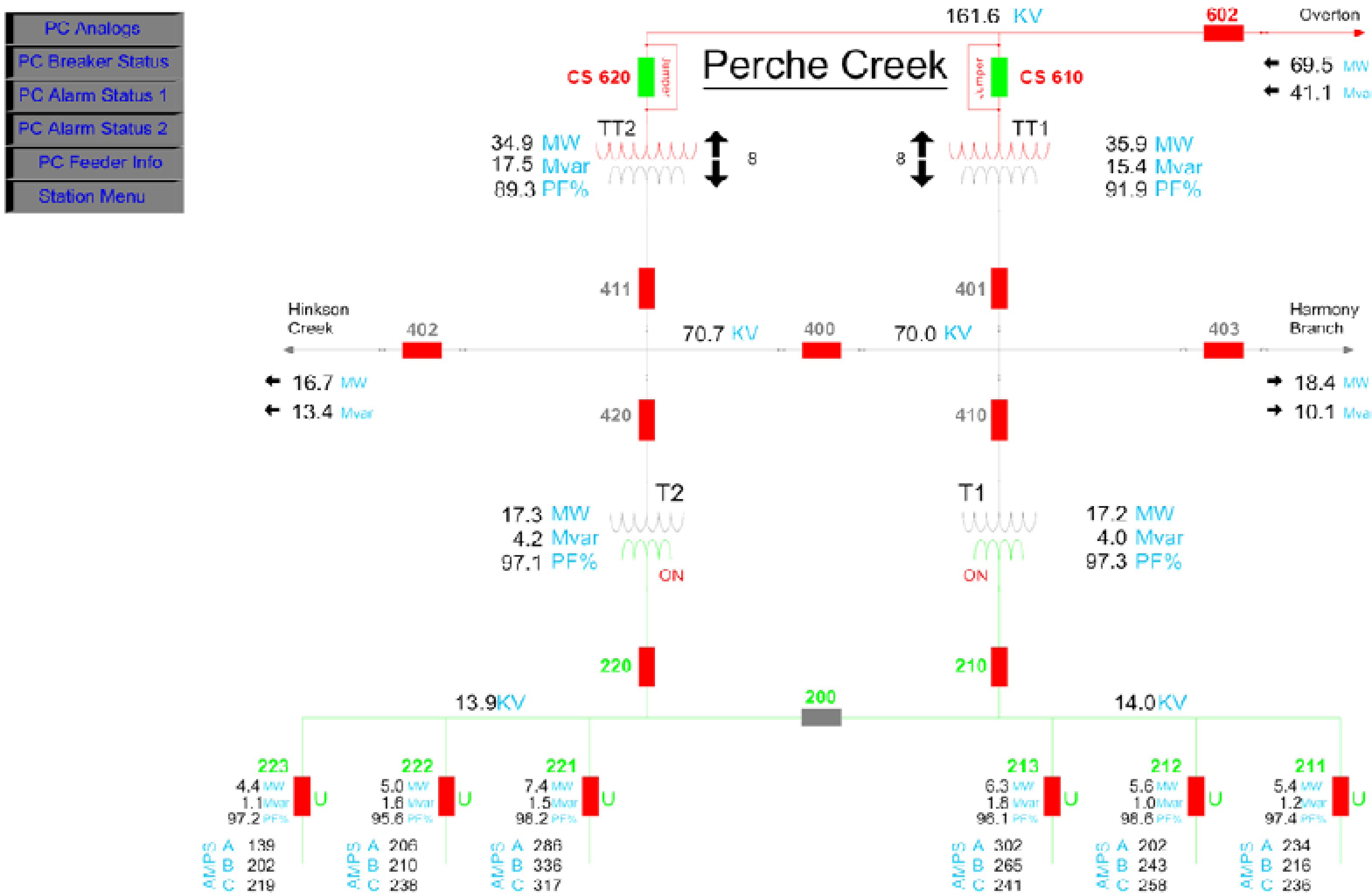
DHC@WLDB00366



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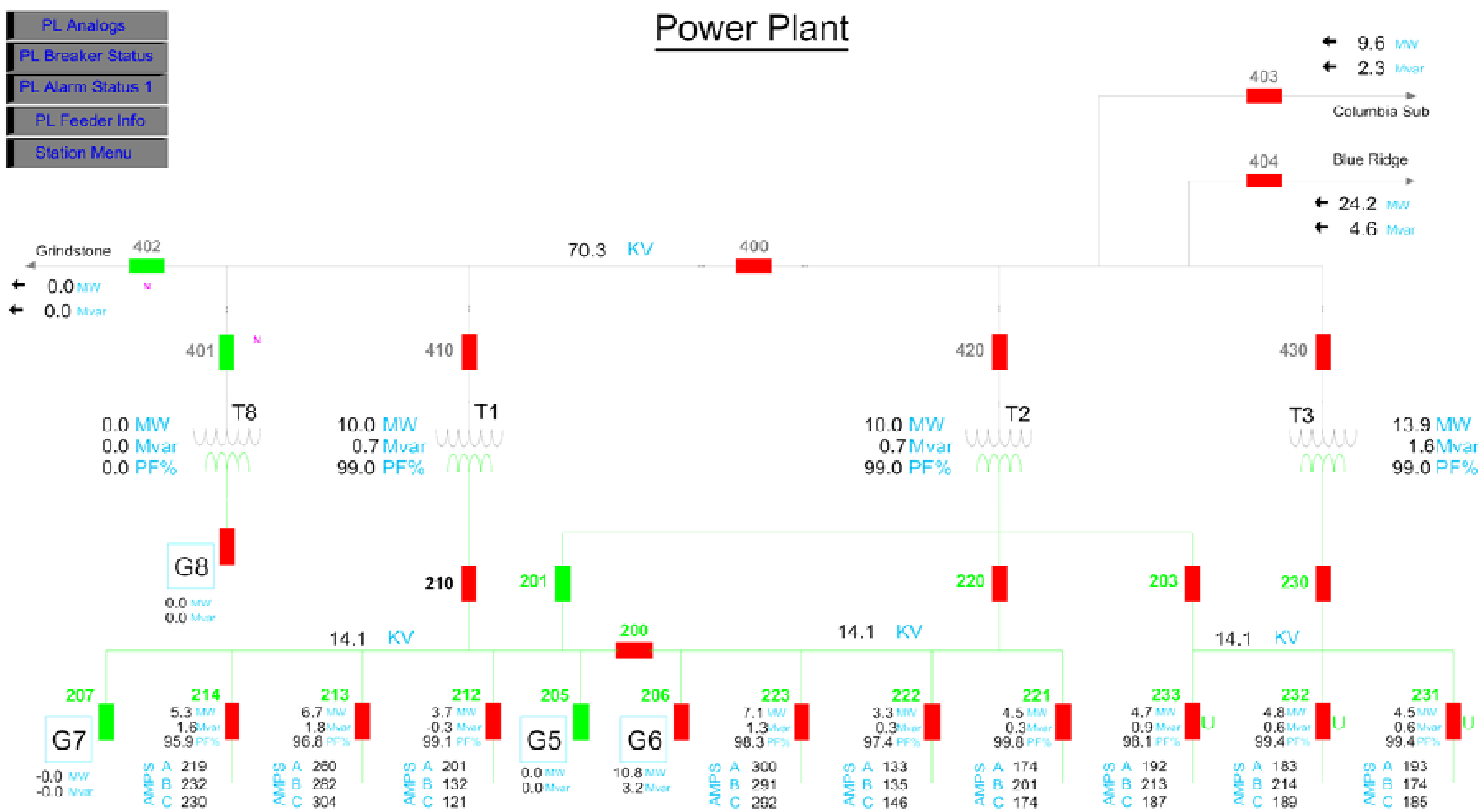

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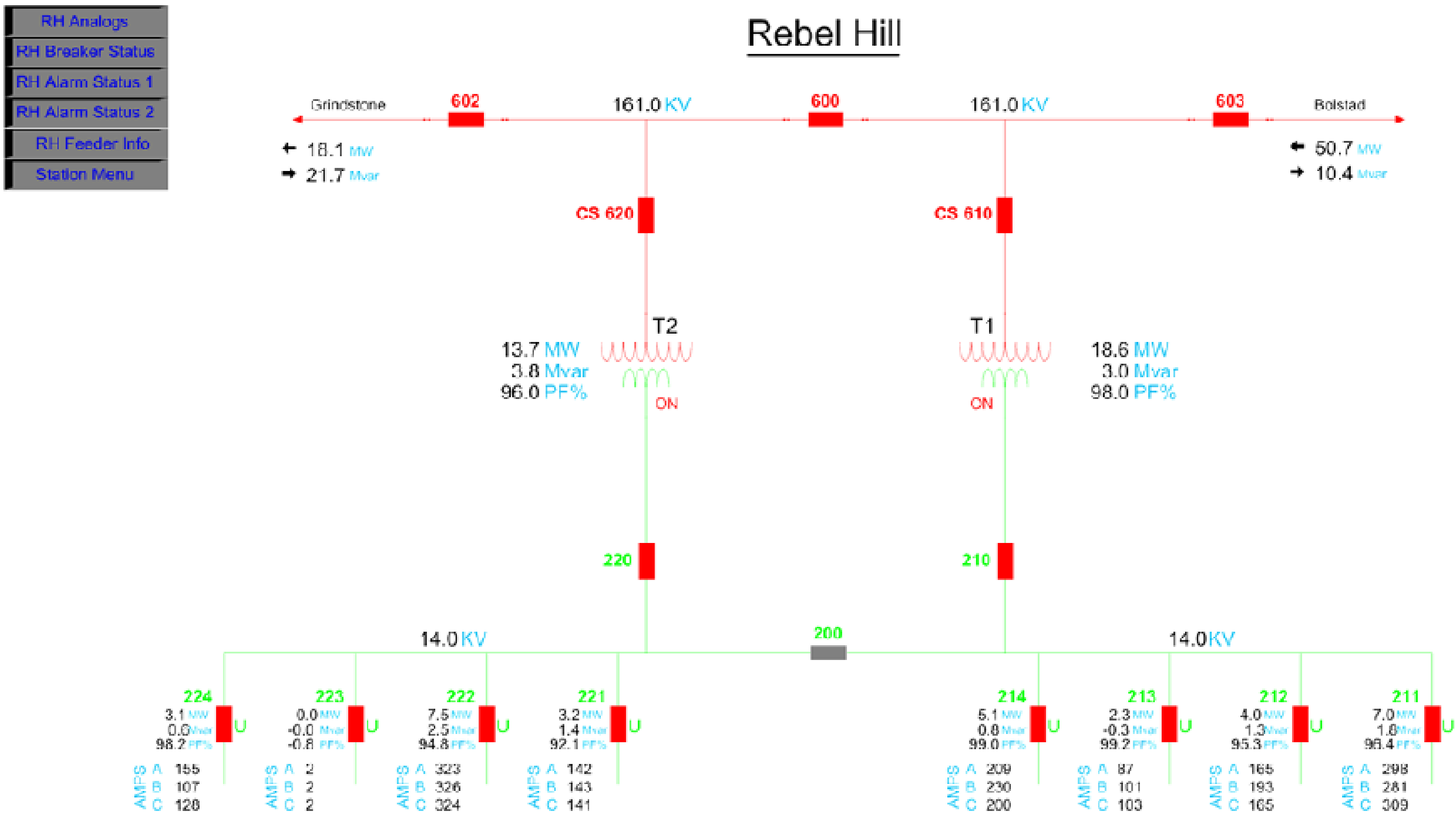
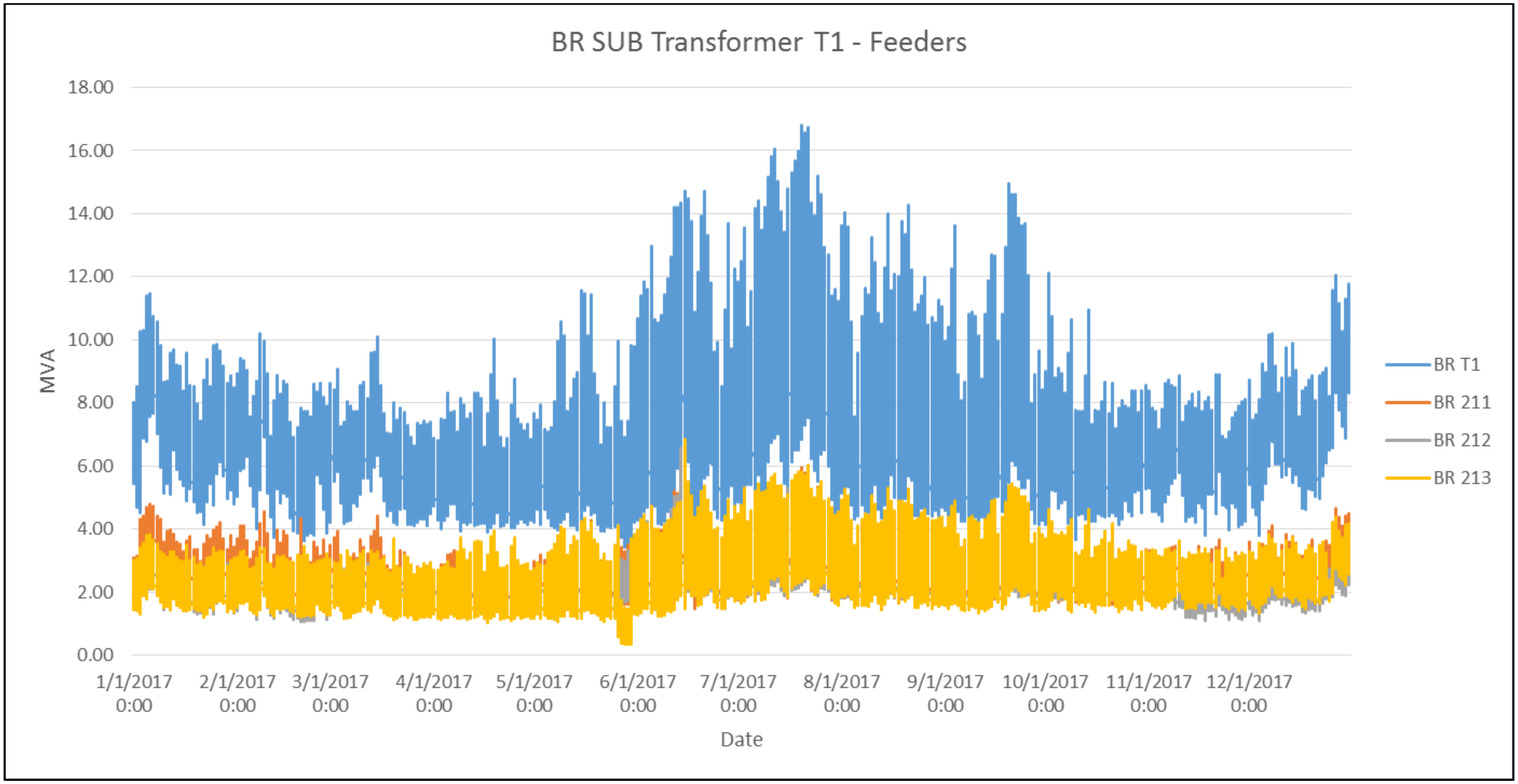
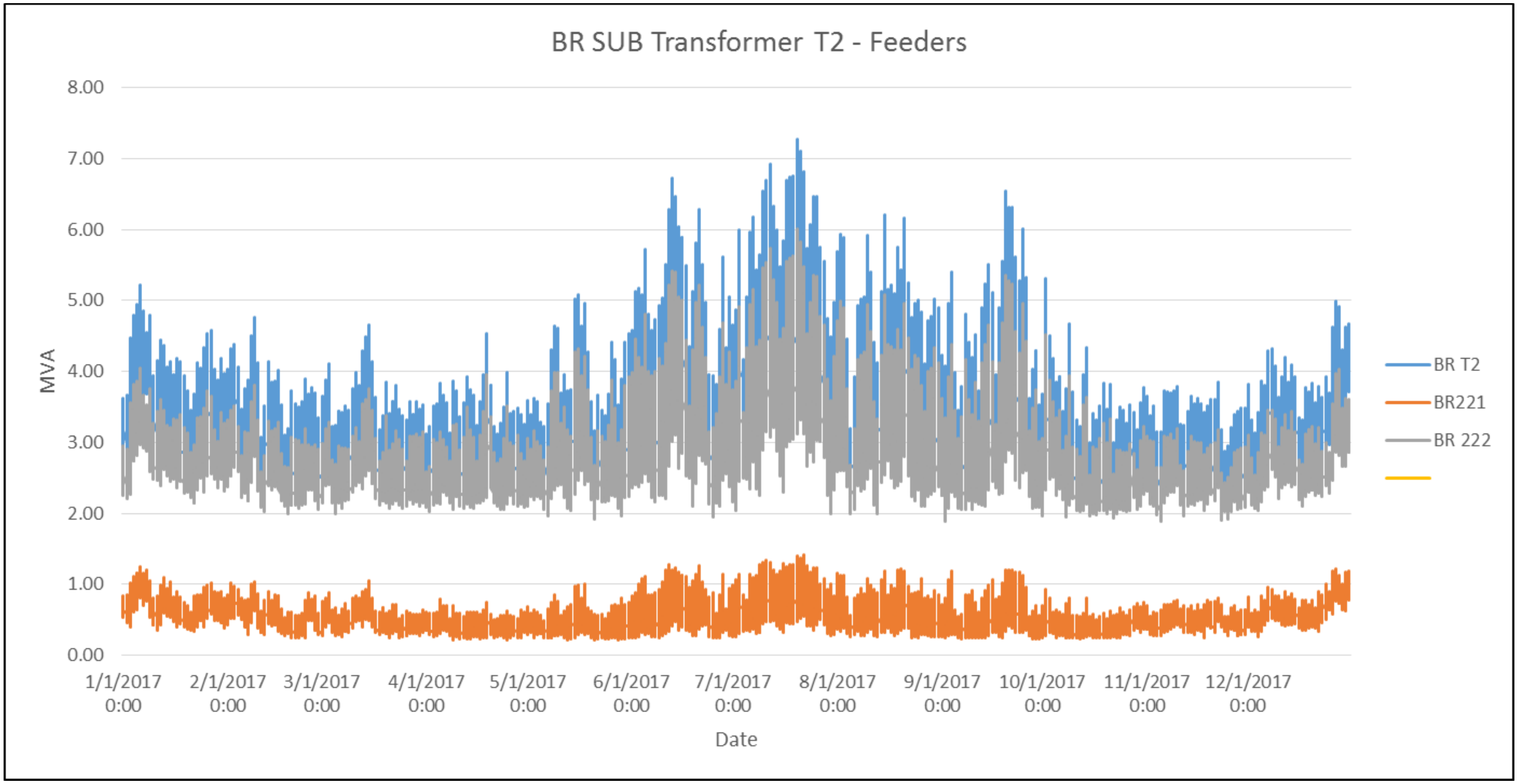
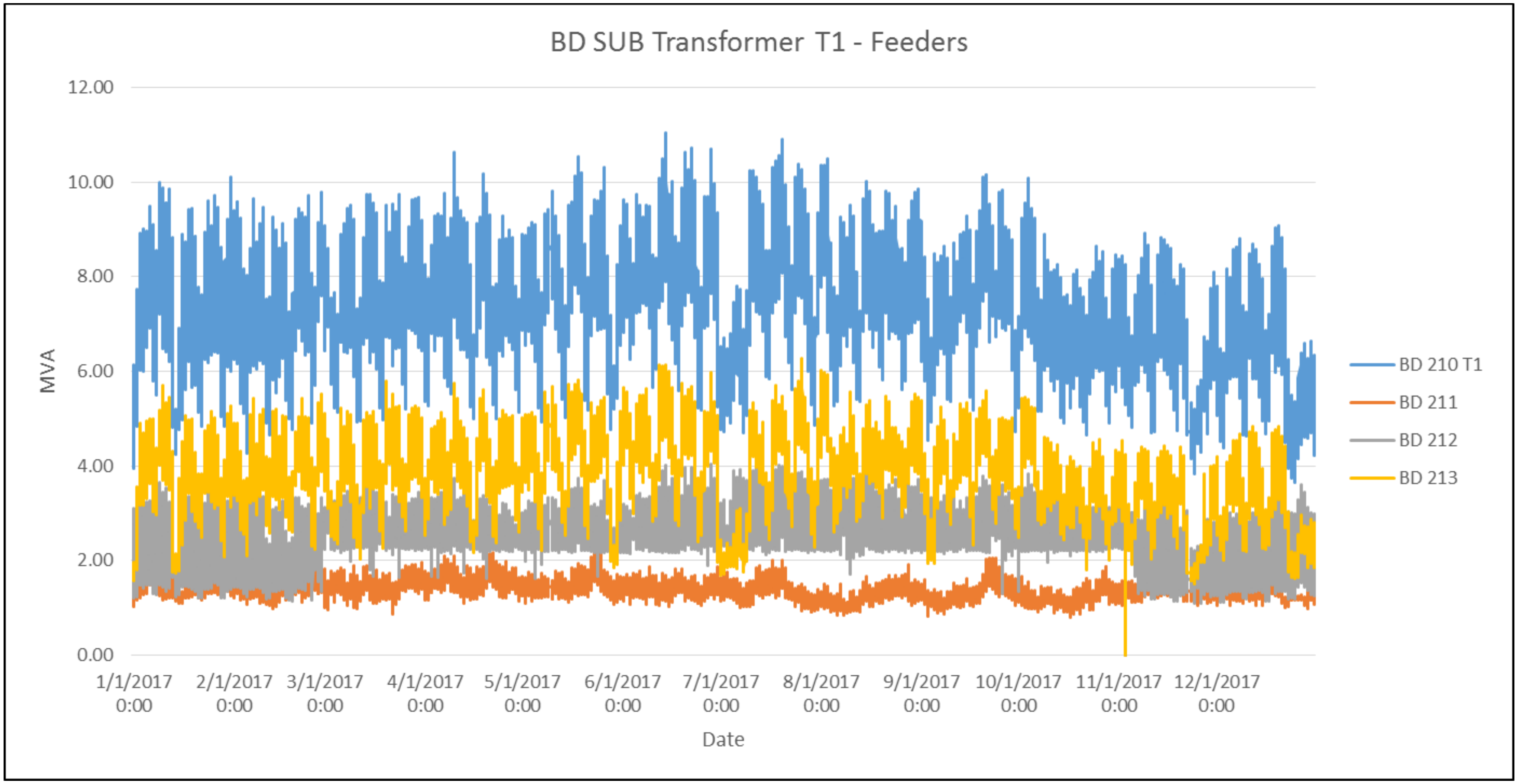
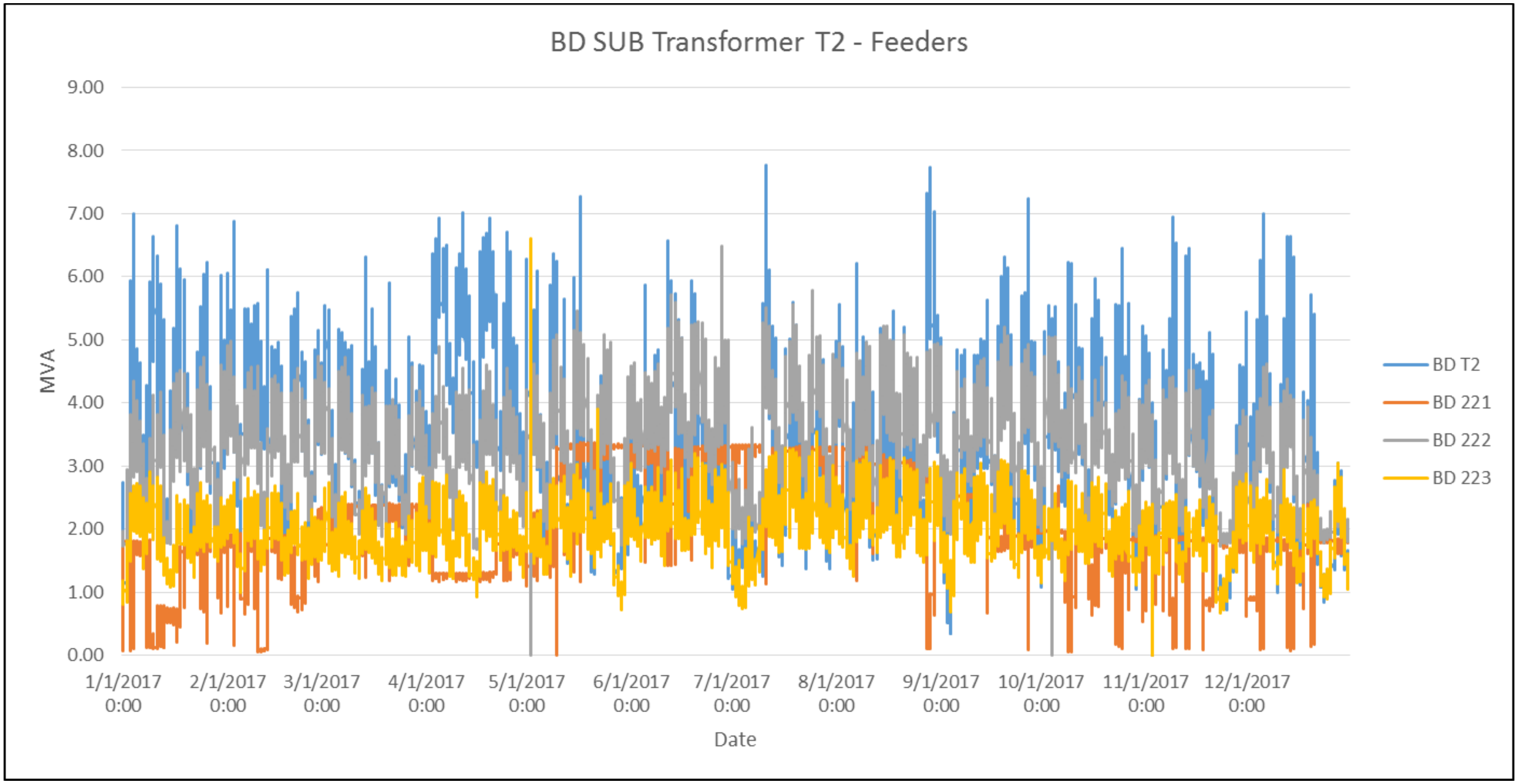


APPENDIX B: SUBSTATION TRANSFORMER AND CIRCUIT LOAD PROFILES




BR SUB Transformer T2 - Feeders
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
BR T2
BR221
BR 222


BD SUB Transformer T1 - Feeders
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
BD 210 T1
BD 211
BD 212
BD 213


BD SUB Transformer T2 - Feeders
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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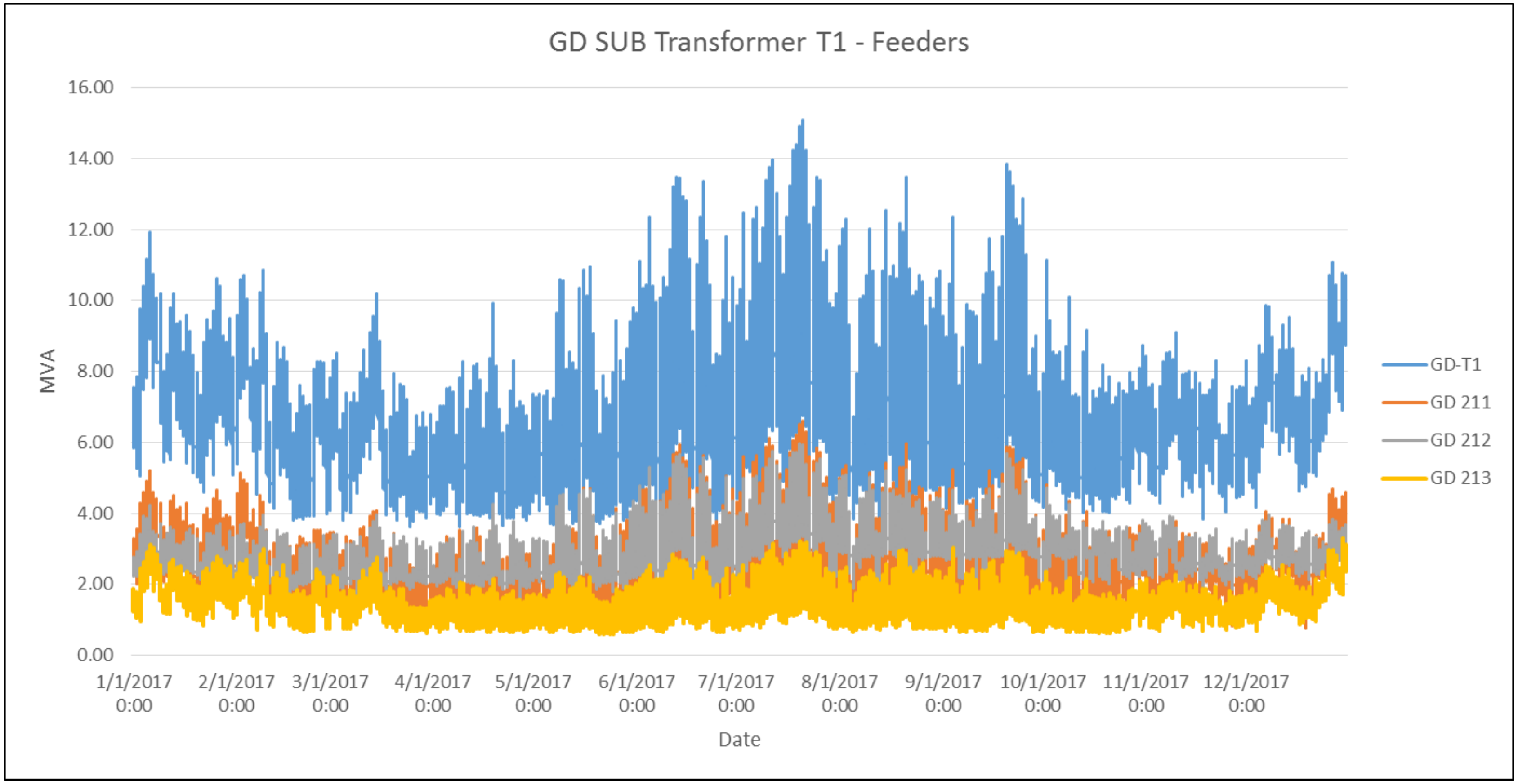
11/1/2017 0:00
12/1/2017 0:00
Date
BD T2
BD 221
BD 222
BD 223


GD SUB Transformer T1 - Feeders
MVA
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
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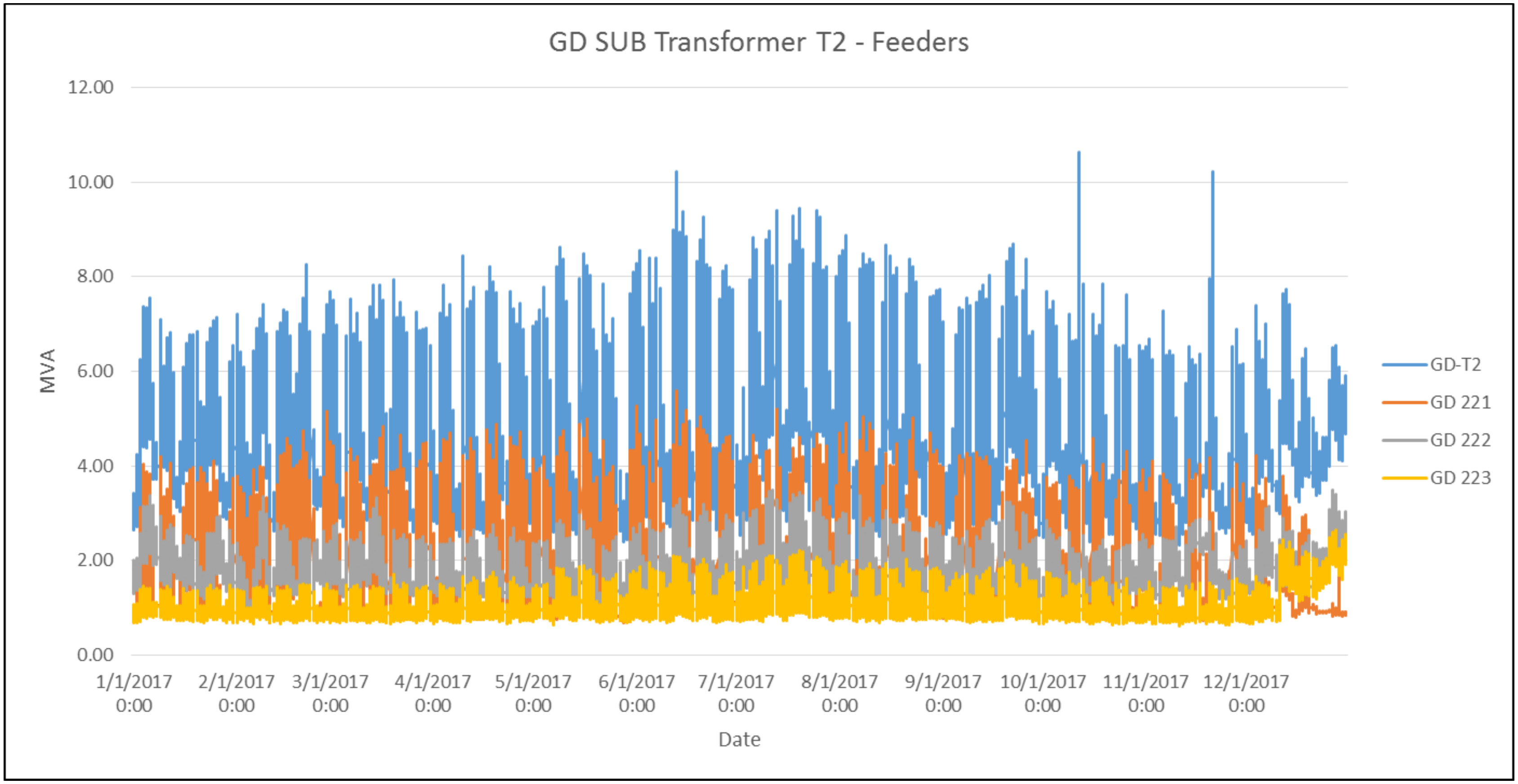
11/1/2017 0:00
12/1/2017 0:00
Date
GD-T1
GD 211
GD 212
GD 213


GD SUB Transformer T2 - Feeders
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
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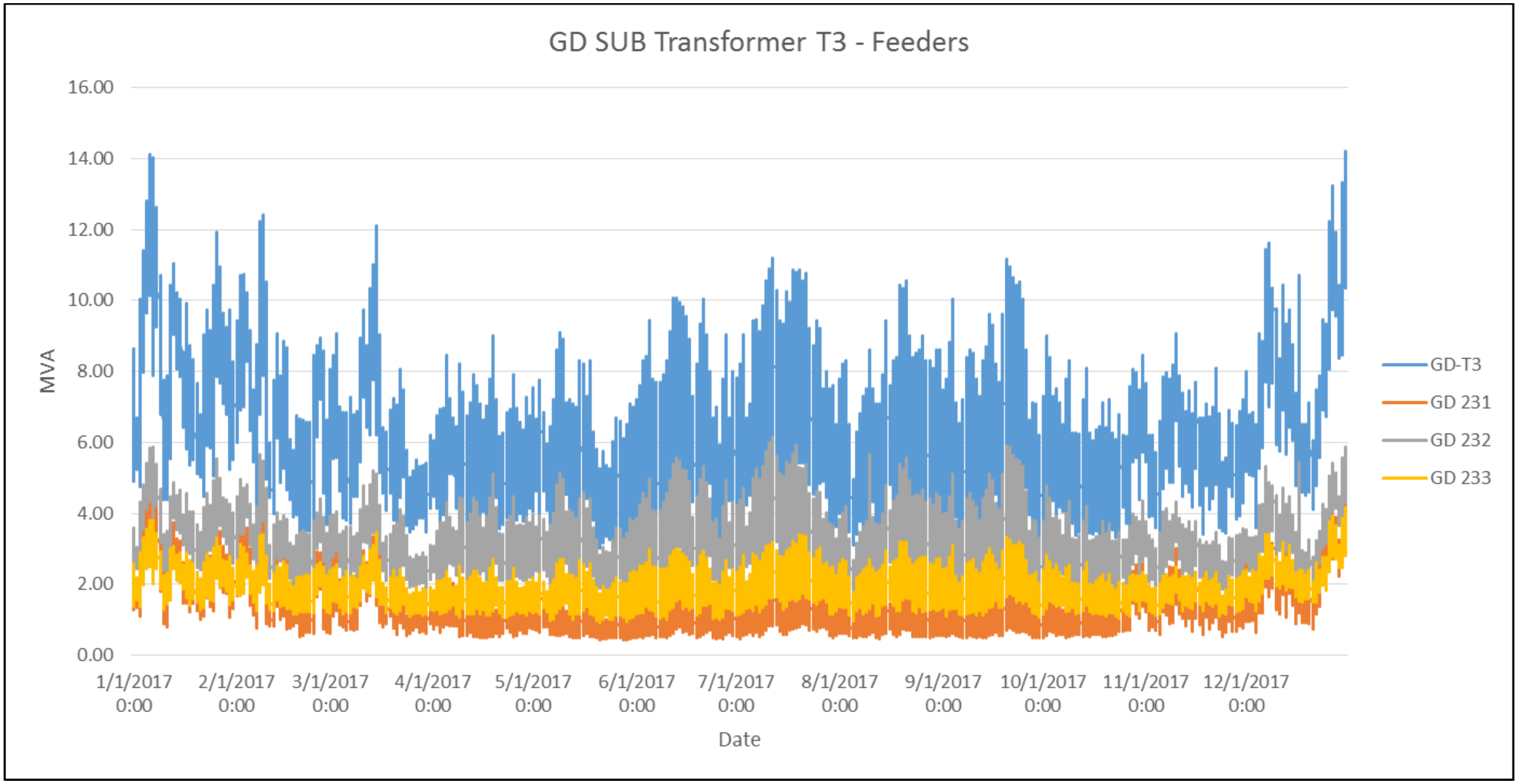
11/1/2017 0:00
12/1/2017 0:00
Date
GD-T2
GD 221
GD 222
GD 223


GD SUB Transformer T3 - Feeders
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
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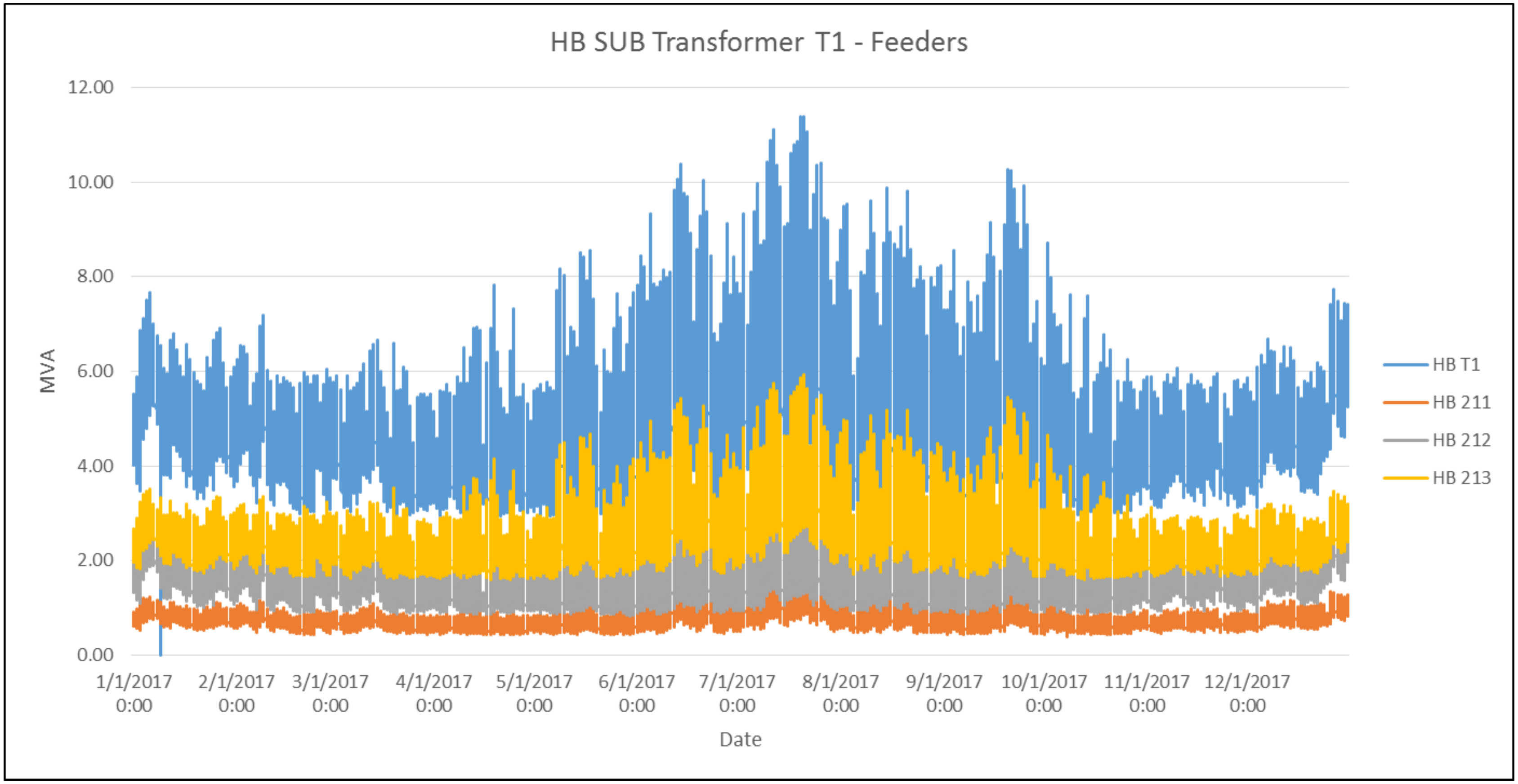
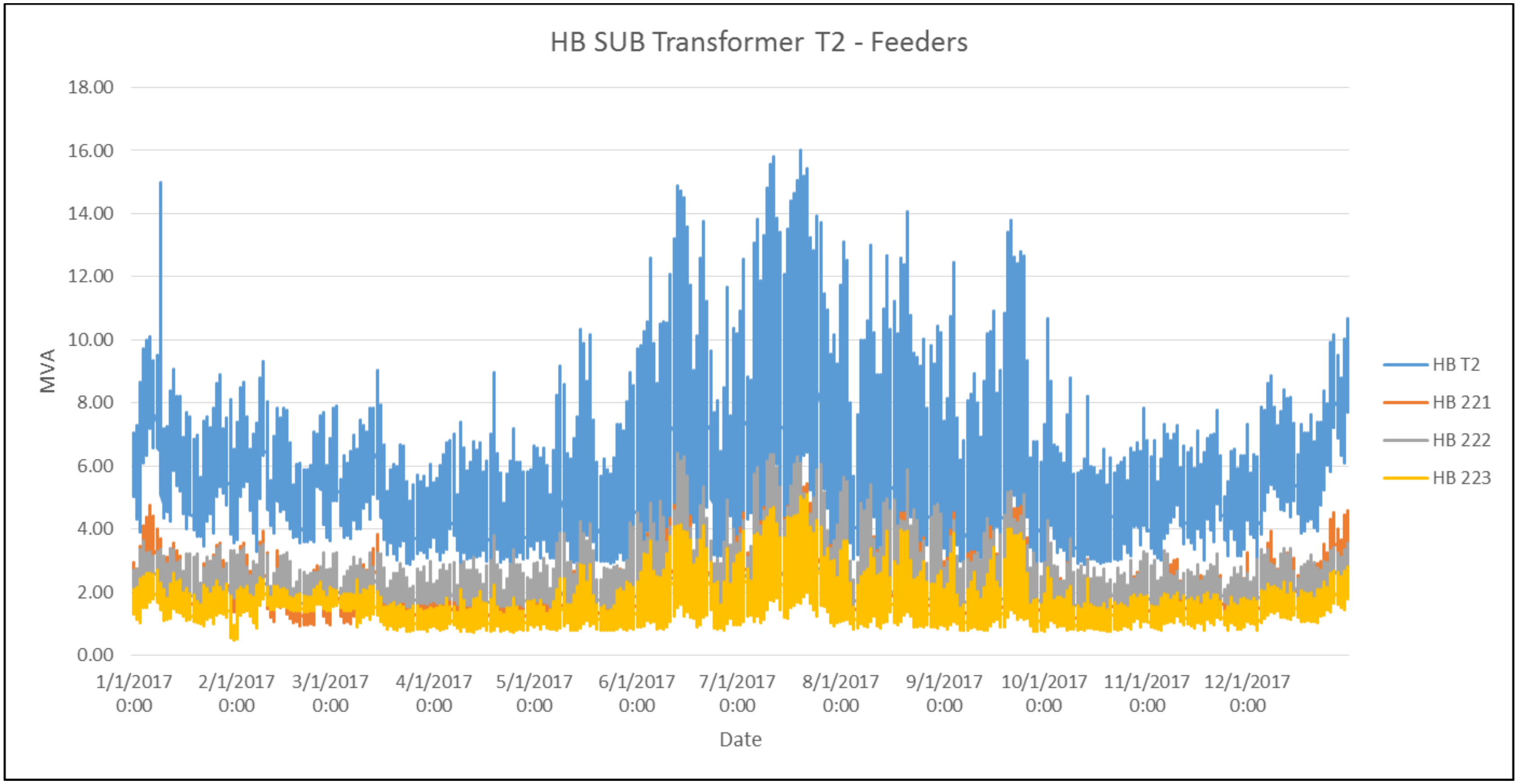
11/1/2017 0:00
12/1/2017 0:00
Date
GD-T3
GD 231
GD 232
GD 233


HB SUB Transformer T1 - Feeders
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
HB T1
HB 211
HB 212
HB 213


HB SUB Transformer T2 - Feeders
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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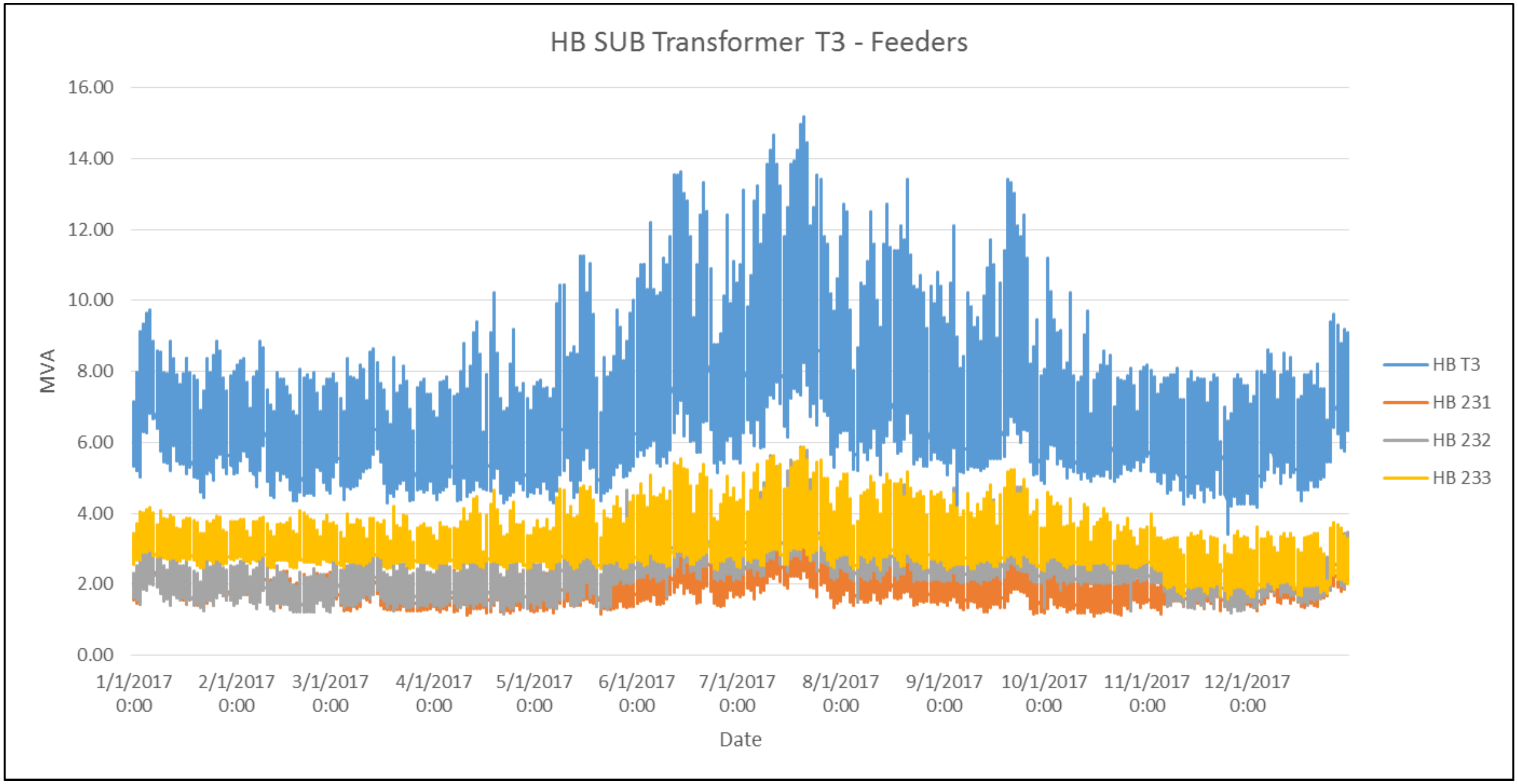
Date
HB T2
HB 221
HB 222
HB 223


HB SUB Transformer T3 - Feeders
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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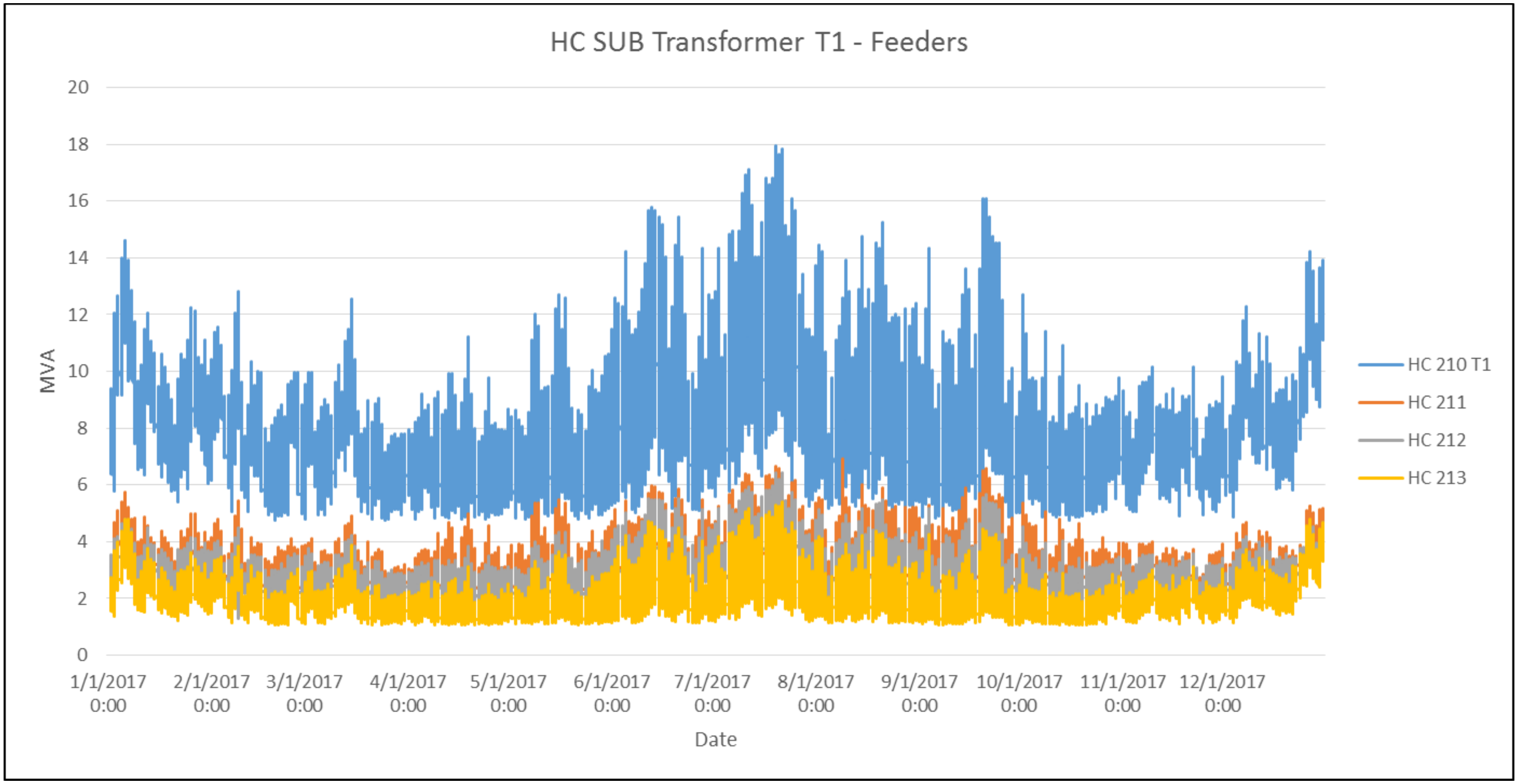
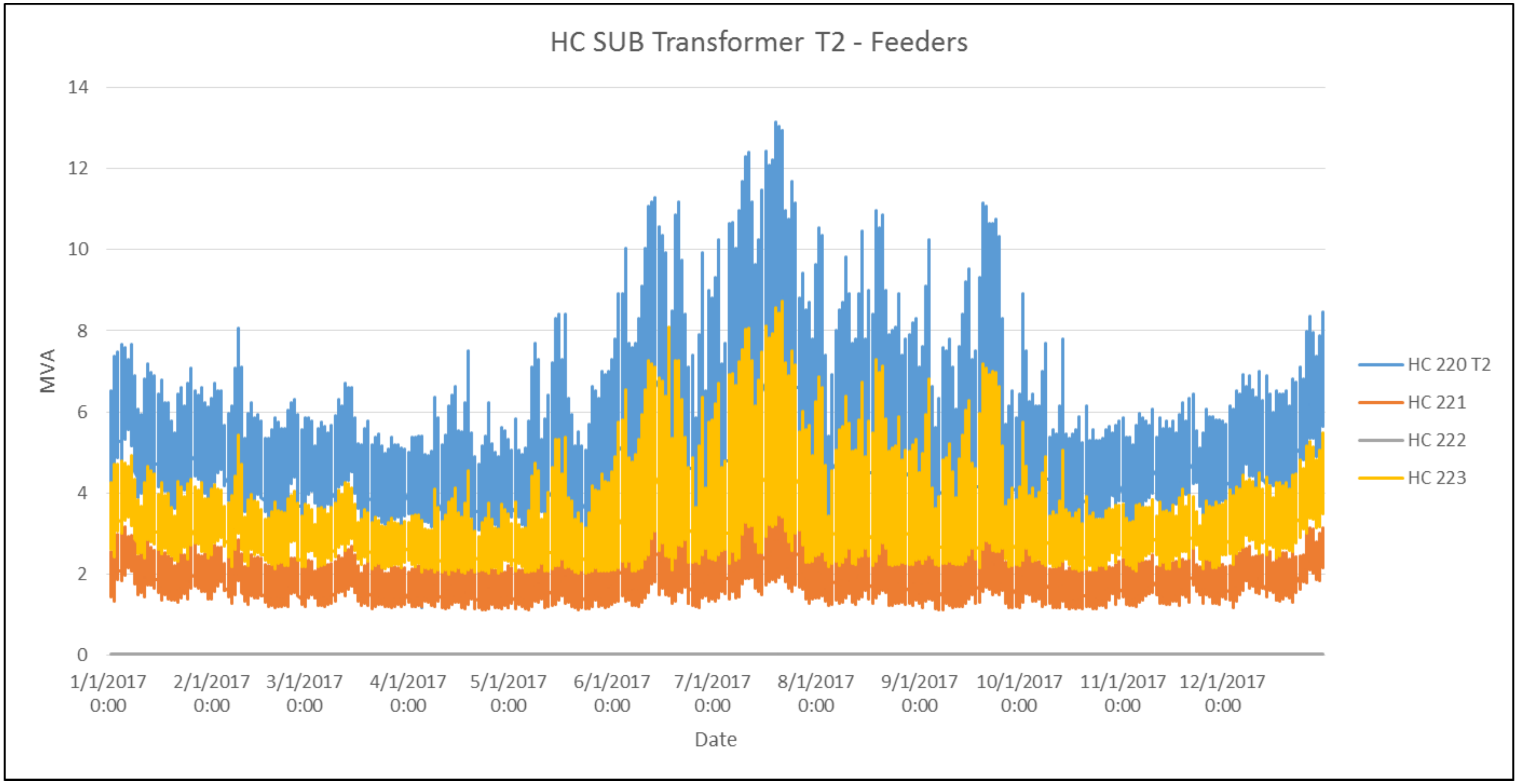
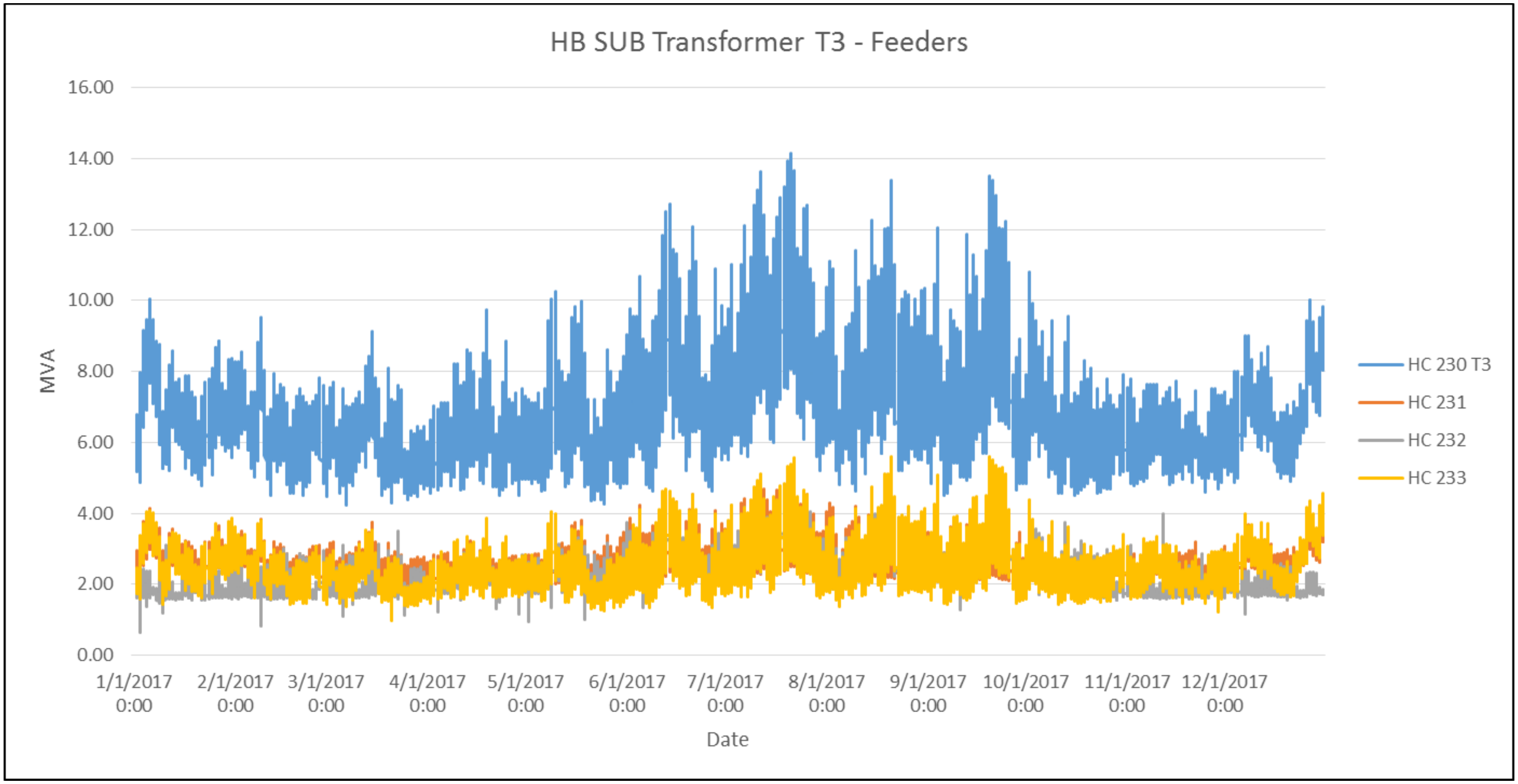
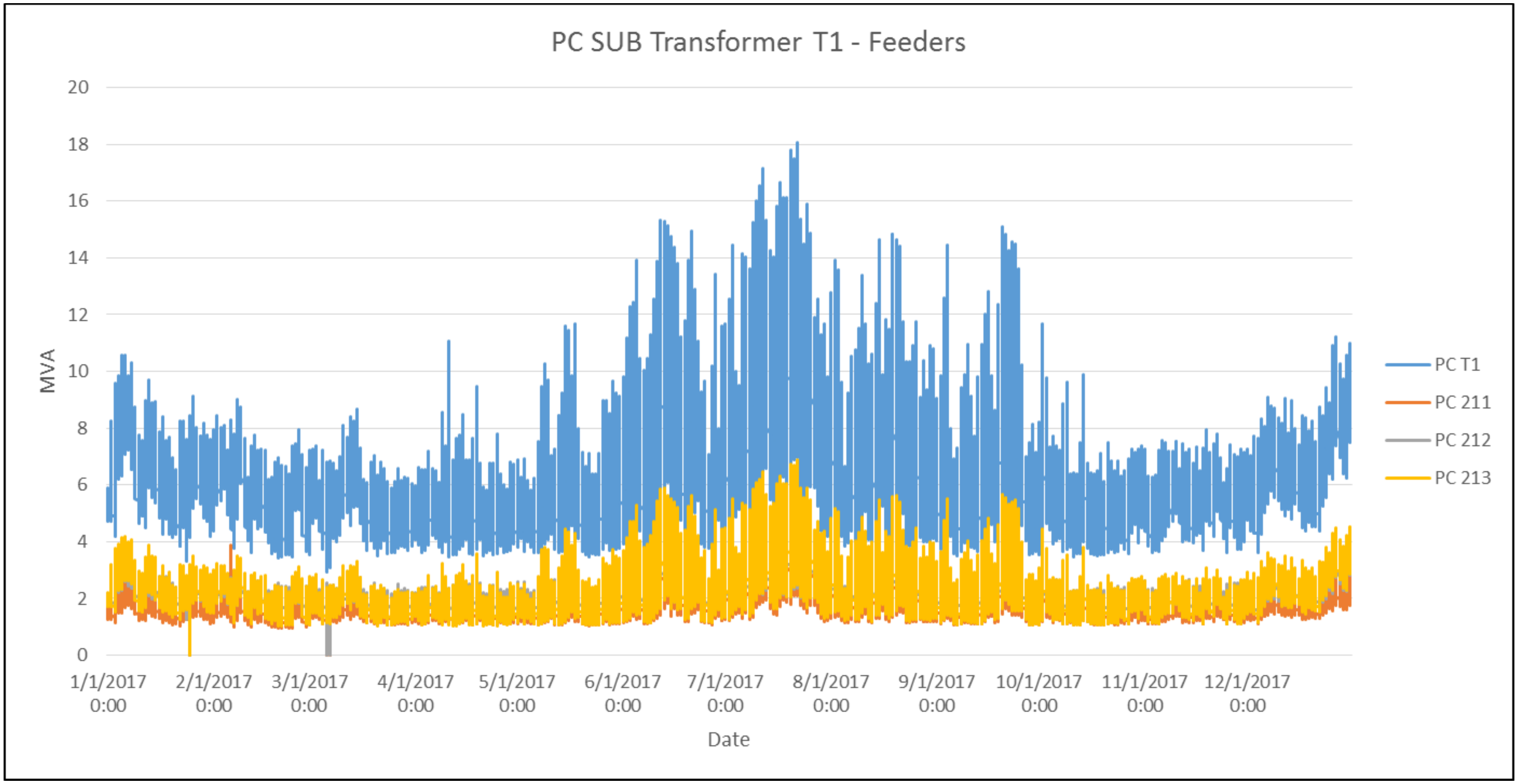
12/1/2017 0:00
Date
HB T3
HB 231
HB 232
HB 233


HC SUB Transformer T1 - Feeders
20
18
16
14
12
10
8
6
4
2
0
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
HC 210 T1
HC 211
HC 212
HC 213


HC SUB Transformer T2 - Feeders
MVA
14
12
10
8
6
4
2
0
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
HC 220 T2
HC 221
HC 222
HC 223


HB SUB Transformer T3 - Feeders
MVA
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
HC 230 T3
HC 231
HC 232
HC 233


PC SUB Transformer T1 - Feeders
MVA
20
18
16
14
12
10
8
6
4
2
0
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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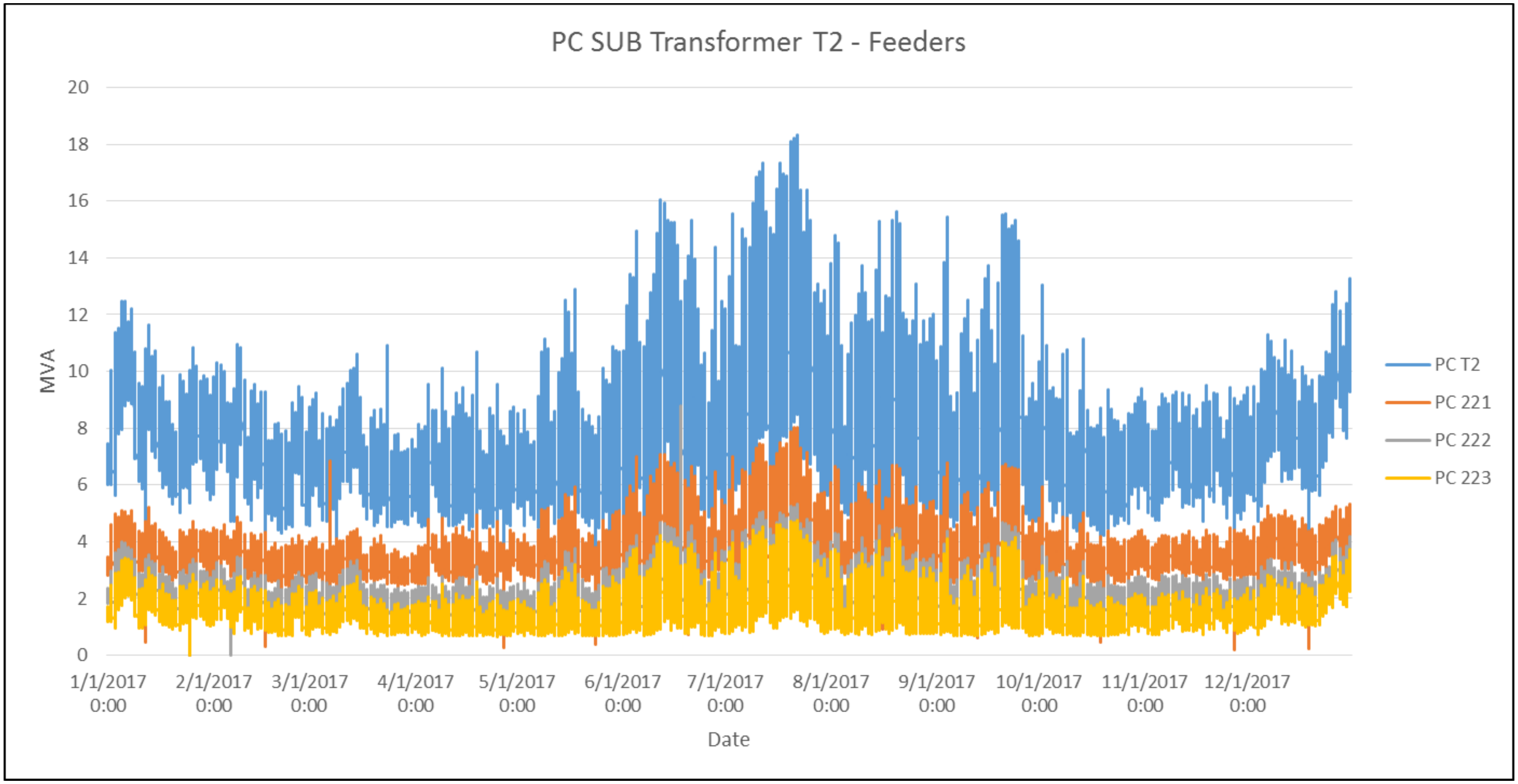
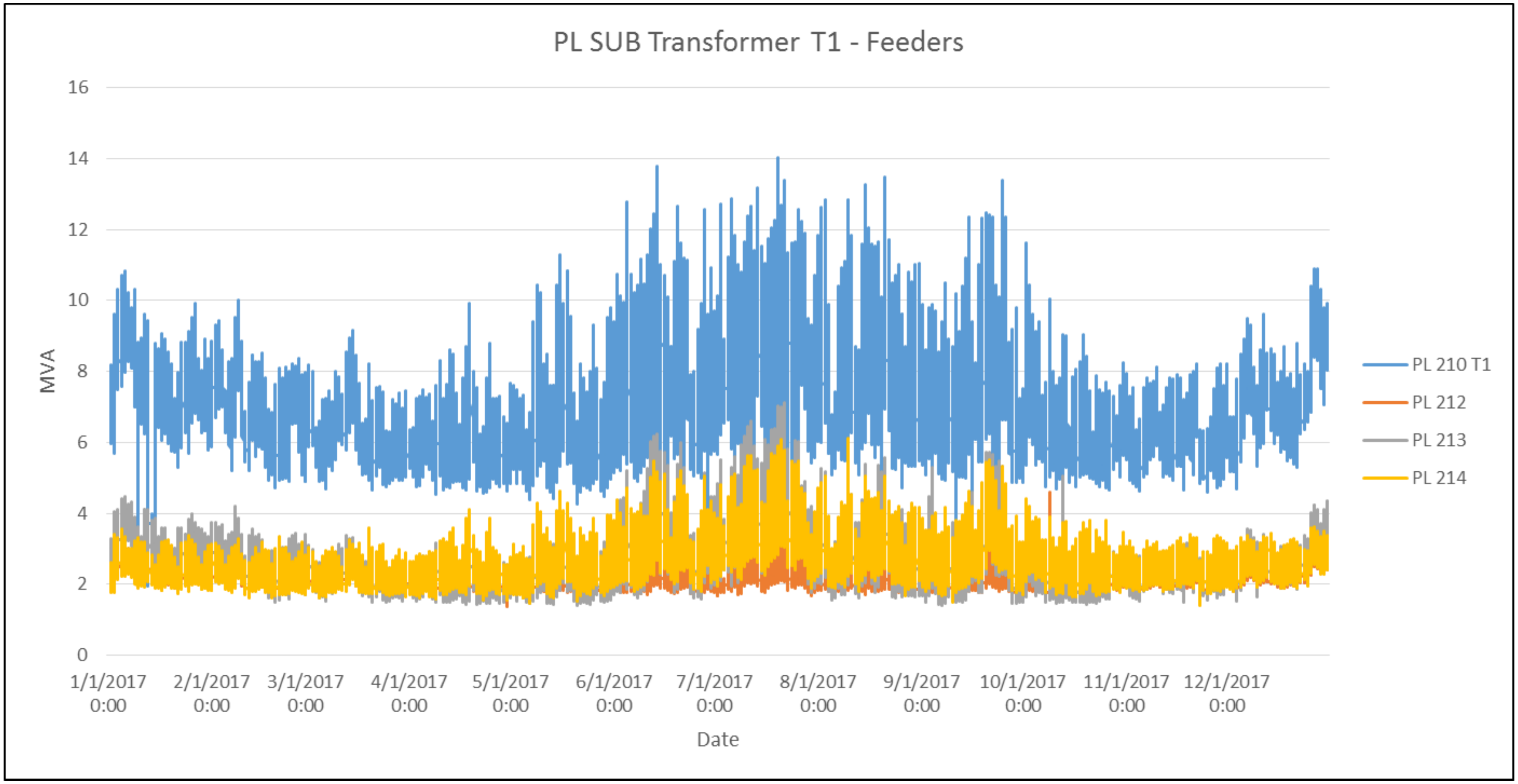
Date
PC T1
PC 211
PC 212
PC 213


PC SUB Transformer T2 - Feeders
MVA
20
18
16
14
12
10
8
6
4
2
0
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
PC T2
PC 221
PC 222
PC 223


PL SUB Transformer T1 - Feeders
16
14
12
10
8
6
4
2
0
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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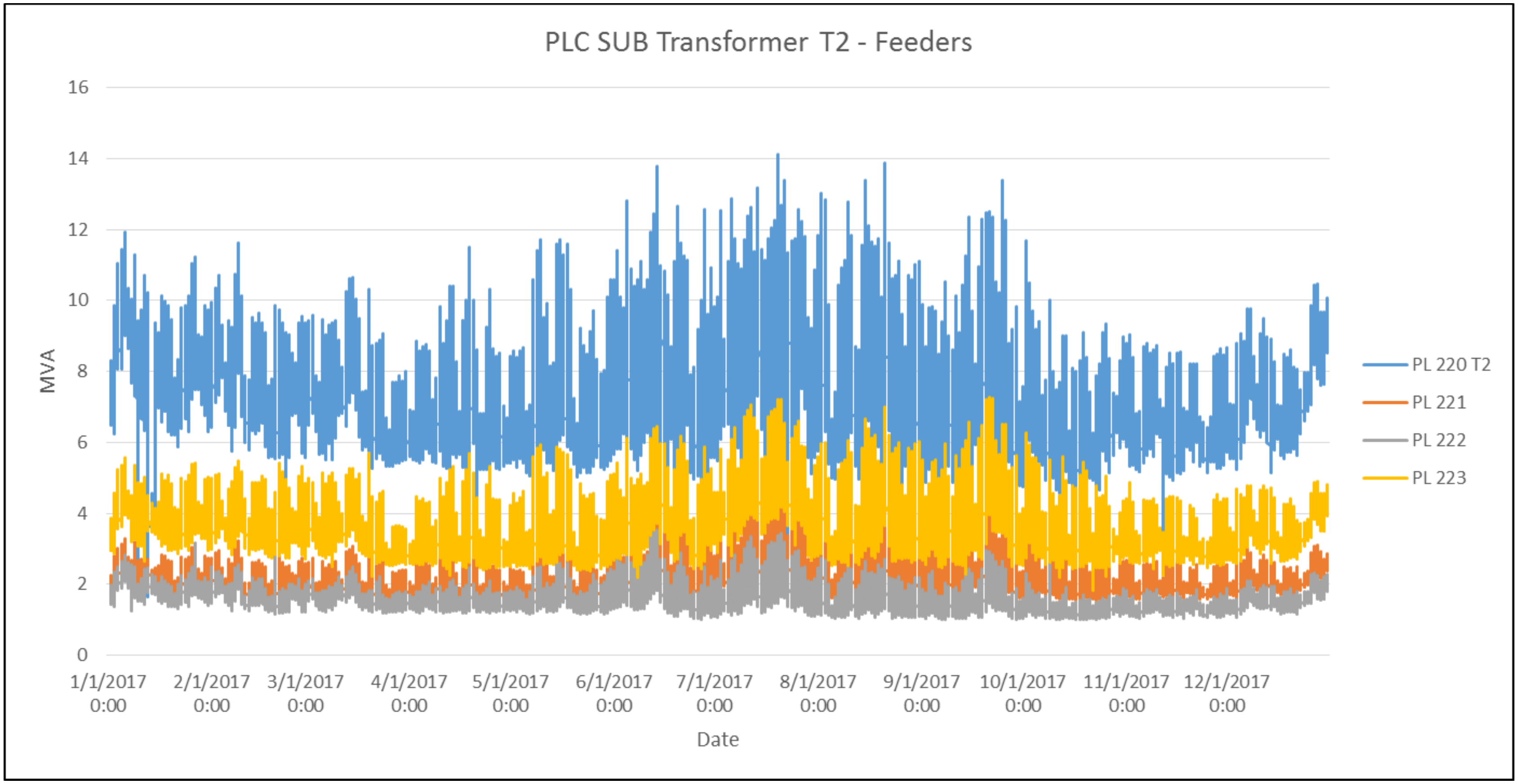
12/1/2017 0:00
Date
PL 210 T1
PL 212
PL 213
PL 214


PLC SUB Transformer T2 - Feeders
16
14
12
10
8
6
4
2
0
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
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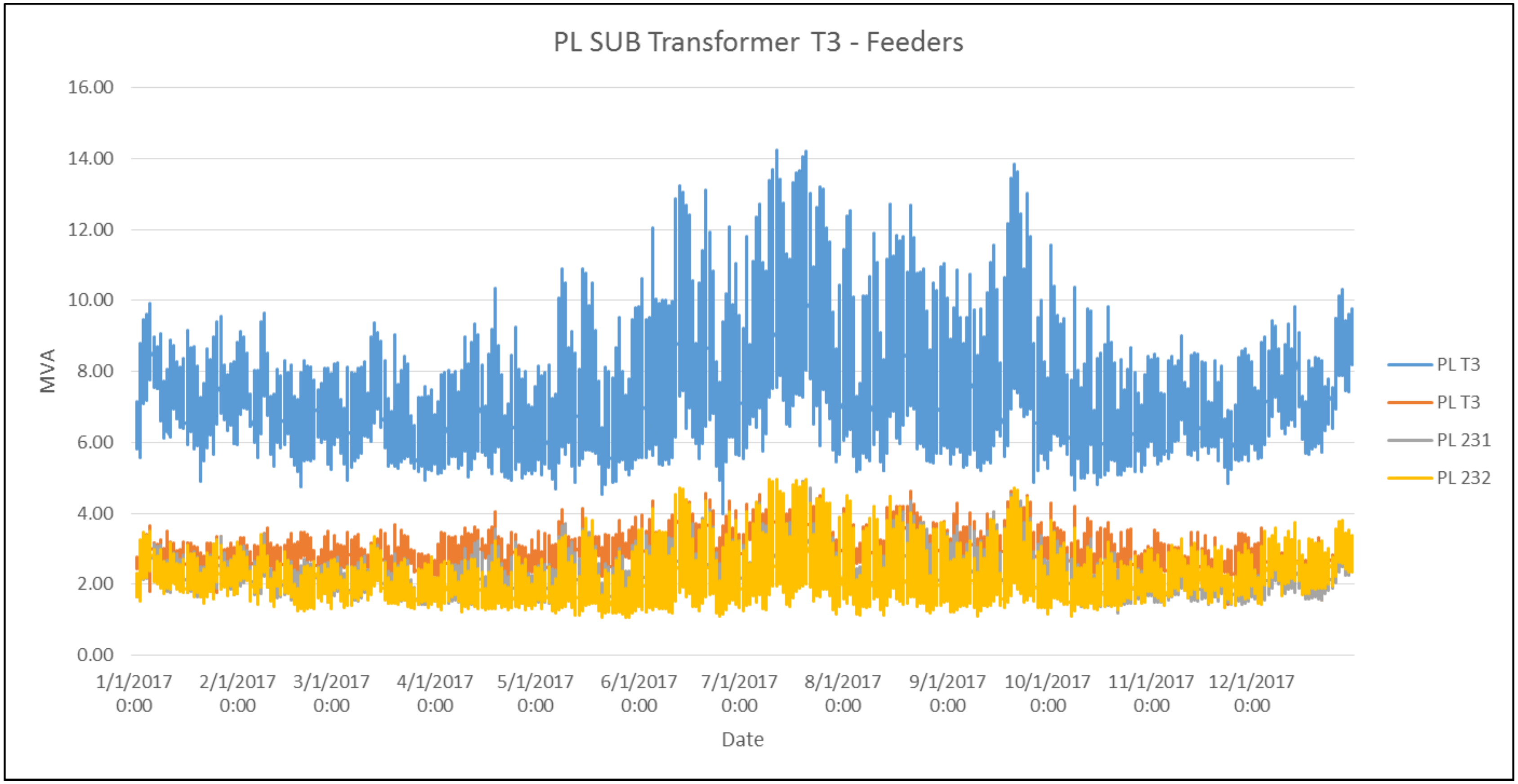
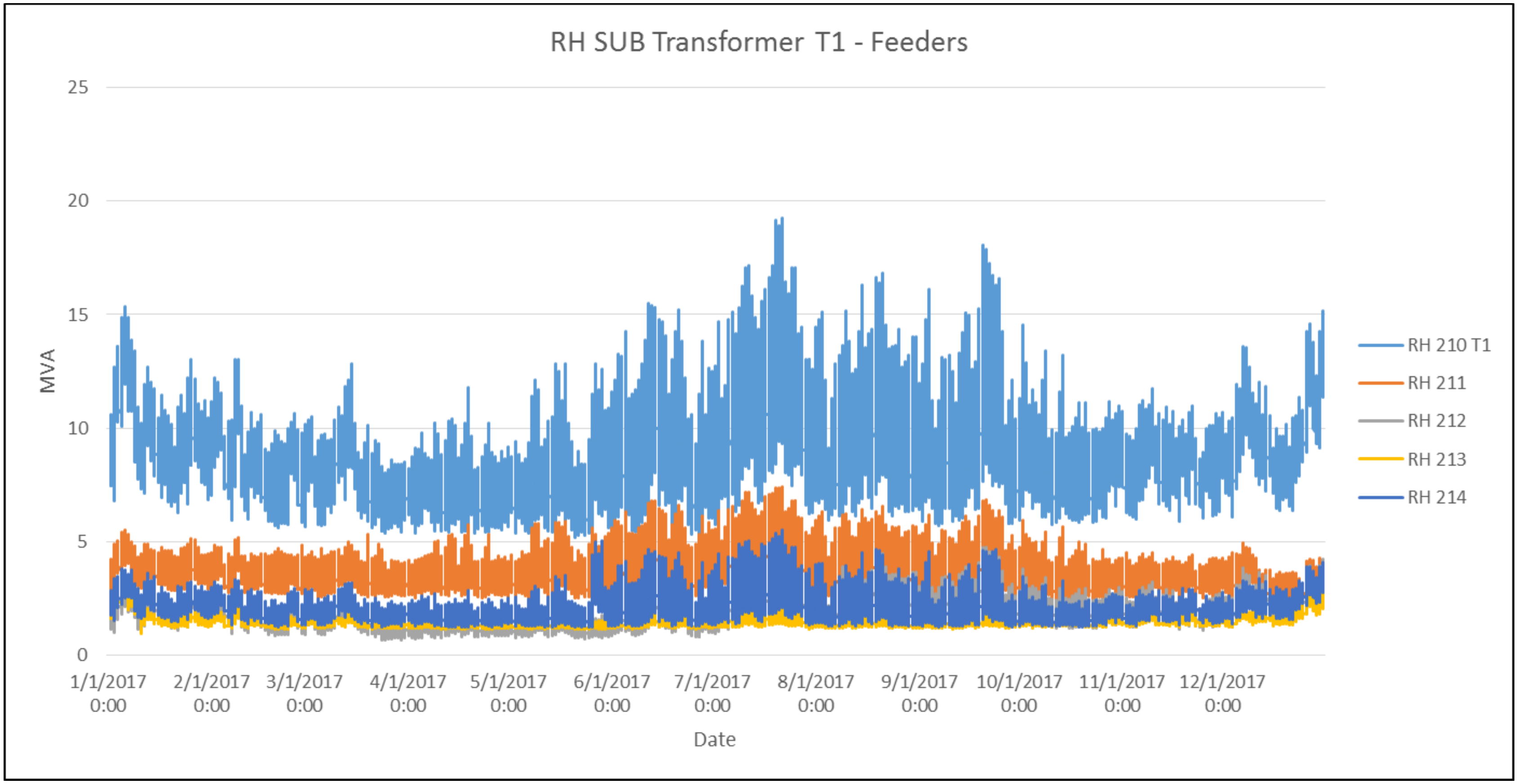
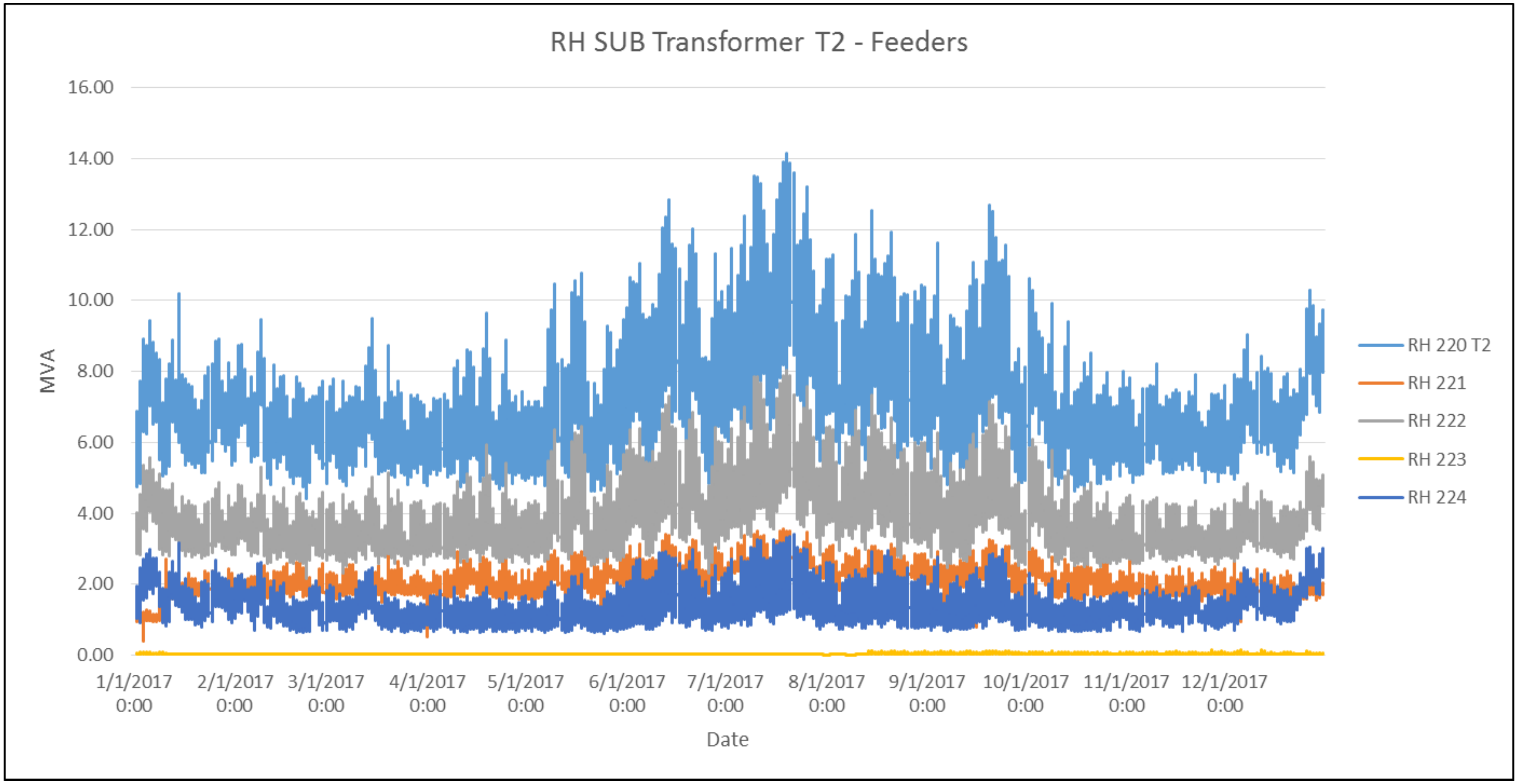
Date
PL 220 T2
PL 221
PL 222
PL 223


PL SUB Transformer T3 - Feeders
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
PL T3
PL T3
PL 231
PL 232

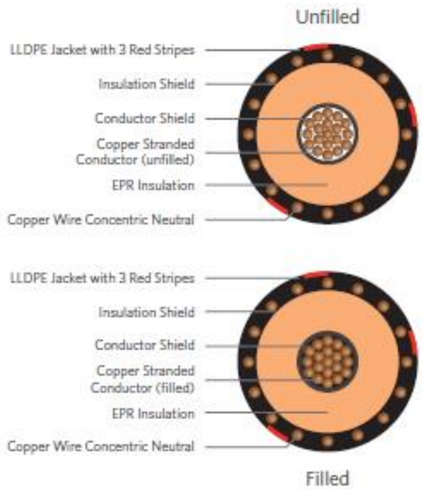

RH SUB Transformer T1 - Feeders
25
20
15
10
5
0
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
RH 210 T1
RH 211
RH 212
RH 213
RH 214


RH SUB Transformer T2 - Feeders
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
MVA
1/1/2017 0:00
2/1/2017 0:00
3/1/2017 0:00
4/1/2017 0:00
5/1/2017 0:00
6/1/2017 0:00
7/1/2017 0:00
8/1/2017 0:00
9/1/2017 0:00
10/1/2017 0:00
11/1/2017 0:00
12/1/2017 0:00
Date
RH 220 T2
RH 221
RH 222
RH 223
RH 224

APPENDIX C: CABLE SHEET

EPR/CN/LLDPE Power, Type MV-90 Primary UD, 15kV-35kV

Series E9 (Copper Conductors)



PRODUCT DESCRIPTION

The Medium Voltage Primary Underground Distribution (UD) cables consist of a Copper (filled or unfilled) conductor, covered with ethylene propylene rubber (EPR), a concentric neutral of helically applied copper wires, and a linear low-density polyethylene (LLDPE) jacket with 3 extruded red stripes.

APPLICATIONS

- Suitable for underground primary power applications
- For wet or dry locations
- For direct burial or in duct

FEATURES

- High dielectric strength
- Low moisture absorption
- Low dielectric loss
- Excellent resistance to treeing
- Jacket is sunlight-resistant
- Designed to operate continuously at a conductor temperature not exceeding
  - 105°C for normal operations
  - 140°C for emergency overload
  - 250°C for short circuit

MARKETS

SPECIFICATIONS	
Conductor Count	1 conductor
Conductor	Fully annealed bare copper Class B compressed strand (filled or unfilled)
Gauge Sizes	**Filled**: Available in 2 AWG through 1000 kcmil **Unfilled**: Available in 2 AWG through 1000 kcmil
Conductor Strand Shield	Extruded thermoset semi-conducting polymer over the conductor
Insulation	Ethylene Propylene Rubber (EPR)
Insulation Shield	Extruded thermoset semi-conducting polymer over the insulation
Neutral	Helically applied, annealed, solid bare copper wires
Jacket	Linear Low-Density Polyethylene (LLDPE)
Jacket Marking	00000 FT LS CABLE XXAWG (KCMIL) AL or CU 1/C XXKV XXX% INSUL LEVEL XXXMILS EPR AA X #BB LLDPE JKT MV-90 (UL) MADE IN USA MMDDYYYY
Packaging	Non-returnable wood reels in a variety of lengths and dimensions
Performance Compliances	ASTM B-3 ICEA S-94-649 ICEA T-31-610 (water block compliance) AEIC CS8 UL 1072 (MV-90) RUS U1

PRODUCT KEY

Conductor	Stranding	Voltage	Insulation	Neutral Options	Jacket
Cu	Filled B or B	MV	EPR	RCN or FCN	LLDPE

B-44 LS 800.249.0014 lscns.us

All information, content, data, specifications, packaging and part numbers detailed herein are subject to change. For the most up-to-date information, please visit ***lscns.us****. Purchase of this product is subject exclusively to the then current* ***LS Cable & System U.S.A., Inc. Terms and Conditions of Sale for Energy Cable Products****, which can be found on our website,* ***lscns.us****, or provided to you upon request.*

Rev 02/18
Ed 17

Part Number: E9JPT-A65B01CA00

Copper Filled, 15kV 133% I.L., 220-mils Series E9JP

UTILITY & RENEWABLES | LOW VO | MEDIUM VOLTAGE | TECHNICAL INFO

PART NUMBERS AND PHYSICAL CHARACTERISTICS

Part Number	Conductor Size AWG/kcmil	Nominal Conductor Diameter[1] in (mm)	Nominal Insulation Diameter[1] in (mm)	Concentric Neutral No. x AWG	Nominal Jacket Thickness[1] in (mm)	Nominal Overall Diameter[1] in (mm)	Nominal Net Weight[1] lbs/kft (kg/km)	Ampacity Underground Duct[2]	Ampacity Direct Buried[2]
⅓ Reduced Neutral									
E9JPT-025B01CA00	2	0.280 (7.1)	0.77 (19.6)	6 x 14	0.055 (1.40)	1.08 (27.4)	671 (1,000)	177	241
E9JPT-015B01CA00	1	0.319 (8.1)	0.81 (20.6)	7 x 14	0.055 (1.40)	1.12 (28.4)	759 (1,130)	201	272
E9JPT-1A5B01CA00	1/0	0.358 (9.1)	0.85 (21.6)	9 x 14	0.055 (1.40)	1.15 (29.2)	874 (1,302)	229	306
E9JPT-2A5B01CA00	2/0	0.401 (10.2)	0.89 (22.7)	11 x 14	0.055 (1.40)	1.20 (30.5)	1,009 (1,504)	260	343
E9JPT-3A5B01CA00	3/0	0.451 (11.5)	0.94 (23.9)	14 x 14	0.055 (1.40)	1.25 (31.8)	1,180 (1,759)	295	380
E9JPT-4A5B01CA00	4/0	0.507 (12.9)	1.00 (25.4)	18 x 14	0.055 (1.40)	1.30 (33.0)	1,397 (2,081)	334	418
E9JPT-A15B01CA00	250	0.552 (14.0)	1.06 (26.8)	21 x 14	0.055 (1.40)	1.38 (35.1)	1,612 (2,402)	366	445
E9JPT-A35B01CA00	350	0.654 (16.6)	1.16 (29.4)	29 x 14	0.055 (1.40)	1.48 (37.7)	2,109 (3,143)	437	498
E9JPT-A65B01CA00	500	0.781 (19.8)	1.29 (32.6)	26 x 12	0.055 (1.40)	1.66 (42.2)	2,937 (4,376)	516	547
E9JPT-B25B01CA00	750	0.958 (24.3)	1.48 (37.5)	25 x 10	0.080 (2.04)	1.90 (48.3)	4,132 (6,156)	603	610
Full Neutral									
E9JPM-025B01CA00	2	0.280 (7.1)	0.77 (19.6)	16 x 14	0.055 (1.40)	1.07 (27.2)	789 (1,175)	173	234
E9JPM-015B01CA00	1	0.319 (8.1)	0.81 (20.6)	20 x 14	0.055 (1.40)	1.12 (28.4)	943 (1,405)	199	266
E9JPM-1A5B01CA00	1/0	0.358 (9.1)	0.85 (21.6)	25 x 14	0.055 (1.40)	1.15 (29.2)	1,092 (1,628)	226	302
E9JPM-2A5B01CA00	2/0	0.401 (10.2)	0.89 (22.7)	32 x 14	0.055 (1.40)	1.19 (30.3)	1,324 (1,972)	259	342
E9JPM-3A5B01CA00	3/0	0.451 (11.5)	0.94 (23.9)	25 x 14	0.055 (1.40)	1.26 (32.0)	1,552 (2,313)	294	388
E9JPM-4A5B01CA00	4/0	0.507 (12.9)	1.00 (25.4)	32 x 12	0.055 (1.40)	1.30 (33.0)	1,870 (2,786)	335	439

[1]The dimensions and weights shown are nominal and subject to industry standards and manufacturing tolerances. Other designs available upon request.
[2]Ampacities: ⅓ Reduced Neutral, triplexed - based on ICEA Standards. Full Neutral, single phase - based on 90°C conductor, 20°C ambient, 100% load factor, 36" burial depth, and earth RHO 90.

The catalog information was extracted from:

http://lscns.us/uploadedFiles/Docs/PDF/Catalogs/Energy/EPR-CN-LLDPE-Power-UD-serE9-copper.pdf

APPENDIX D: SUBSTATION AND CIRCUIT LOADING

SUB/Xfmr	kV	Maximum demand			Minimum demand			Power Factor	Load Factor
Feeder	Nominal	MW	MVAR	MVA	MW	MVAR	MVA	(PF)	(LF)
BD T1	13.8	10.93	1.53	11.03	3.91	-2.32	4.54	0.99	67%
BD 211	13.8	2.15	0.28	2.17	0.59	-0.70	0.92	0.99	61%
BD 212	13.8	4.07	-0.25	4.08	0.85	-2.09	2.26	1.00	56%
BD 213	13.8	6.02	1.78	6.28	1.65	-0.34	1.68	0.96	62%
BD T2	13.8	7.73	0.78	7.77	-1.02	-2.28	2.49	0.99	42%
BD 221	13.8	0.36	-1.08	1.14	-3.05	-1.45	3.38	0.88	
BD 222	13.8	6.45	0.74	6.49	0.00	0.00	0.00	0.99	51%
BD 223	13.8	6.47	1.34	6.61	0.63	0.26	0.68	0.98	28%
BR T1	13.8	16.72	1.68	16.80	2.57	-2.26	3.42	0.99	43%
BR 211	13.8	5.91	-0.71	5.95	1.07	-1.24	1.64	0.99	43%
BR 212	13.8	6.54	-0.77	6.59	1.02	-1.34	1.68	0.99	33%
BR 213	13.8	6.77	1.01	6.84	0.31	0.15	0.34	0.99	38%
BR T2	13.8	7.15	1.34	7.27	1.99	-0.75	2.13	0.98	48%
BR 221	13.8	1.35	0.39	1.41	0.22	-0.01	0.22	0.96	41%
BR 222	13.8	5.93	0.96	6.01	1.74	-0.80	1.92	0.99	48%
BR 223	13.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
GD T1	13.8	14.93	2.15	15.09	3.48	-1.00	3.62	0.99	47%
GD211	13.8	6.33	1.86	6.60	0.90	0.26	0.94	0.96	45%
GD212	13.8	5.96	0.11	5.96	1.24	-0.45	1.32	1.00	48%
GD213	13.8	3.09	0.86	3.21	0.58	0.08	0.59	0.96	48%
GD T2	13.8	9.37	4.08	10.22	1.47	-0.49	1.55	0.92	49%
GD221	13.8	4.86	2.75	5.59	0.42	-0.78	0.89	0.87	34%
GD222	13.8	3.46	0.53	3.50	0.84	-0.54	1.00	0.99	52%
GD223	13.8	2.07	0.79	2.22	0.63	0.07	0.63	0.93	55%
GD T3	13.8	11.10	1.40	11.19	2.80	-1.10	3.01	0.99	57%
GD231	13.8	2.48	0.37	2.51	0.38	-0.17	0.42	0.99	46%
GD232	13.8	6.09	0.75	6.14	1.58	-0.95	1.84	0.99	52%
GD233	13.8	3.28	0.96	3.42	0.91	0.14	0.92	0.96	58%

SUB/Transfr	kV	Maximum demand			Minimum demand				
Feeder	Nominal	MW	MVAR	MVA	MW	MVAR	MVA	PF	LF
HB T1	13.8	11.07	2.67	11.39	2.81	-0.65	2.89	0.97	47%
HB 211	13.8	1.95	0.60	2.04	0.42	0.10	0.43	0.96	40%
HB 212	13.8	3.59	0.77	3.67	0.71	-0.42	0.82	0.98	47%
HB 213	13.8	5.79	1.33	5.94	1.54	-0.45	1.60	0.97	46%
HB T2	13.8	15.40	4.40	16.01	2.74	-0.81	2.86	0.96	39%
HB 221	13.8	5.16	1.68	5.43	0.91	0.13	0.92	0.95	42%
HB 222	13.8	6.19	1.66	6.41	1.05	-1.04	1.48	0.97	36%
HB 223	13.8	4.85	1.58	5.10	0.70	0.17	0.72	0.95	32%
HB T3	13.8	15.10	1.50	15.17	3.6	-1.00	3.74	1.00	47%
HB 231	13.8	3.85	1.57	4.16	1.09	0.37	1.15	0.93	40%
HB 232	13.8	5.87	0.24	5.87	1.11	-0.38	1.17	1.00	40%
HB 233	13.8	5.87	0.40	5.88	1.53	-1.89	2.43	1.00	50%
HC T1	13.8	17.80	2.20	17.94	3.80	-2.90	4.78	0.99	45%
HC 211	13.8	6.86	-0.78	6.90	1.00	-0.91	1.35	0.99	48%
HC 212	13.8	6.38	0.70	6.42	1.38	-1.20	1.83	0.99	45%
HC 213	13.8	5.29	1.00	5.38	0.85	-0.64	1.06	0.98	39%
HC T2	13.8	13.00	1.90	13.14	1.10	-0.40	1.17	0.99	40%
HC 221	13.8	4.76	1.02	4.87	1.08	-0.25	1.11	0.98	44%
HC 222	13.8	1.00	0.10	1.00	0.00	0.00	0.00	1.00	
HC 223	13.8	8.57	1.61	8.72	1.63	-1.23	2.04	0.98	38%
HC T3	13.8	13.90	2.60	14.14	4.20	-0.80	4.28	0.98	51%
HC 231	13.8	5.03	0.30	5.04	1.37	-1.37	1.94	1.00	49%
HC 232	13.8	4.11	1.72	4.46	0.90	0.28	0.94	0.92	54%
HC 233	13.8	5.42	1.44	5.61	1.23	0.22	1.25	0.97	47%
PC T1	13.8	17.53	4.28	18.05	3.15	-1.44	3.46	0.97	37%
PC 211	13.8	5.54	1.28	5.69	0.90	-0.57	1.07	0.97	34%
PC 212	13.8	5.61	0.99	5.70	1.16	-0.77	1.39	0.98	41%
PC 213	13.8	6.59	1.95	6.87	1.02	-0.06	1.02	0.96	34%
PC T2	13.8	17.23	4.33	17.77	2.31	-0.25	2.33	0.97	45%
PC 221	13.8	7.84	1.73	8.03	-0.41	-0.29	0.50	0.98	48%
PC 222	13.8	5.08	1.55	5.31	1.16	0.16	1.17	0.96	44%
PC 223	13.8	4.62	1.19	4.77	0.61	-0.23	0.65	0.97	35%

SUB/Transfr Feeder	kV Nominal	Maximum demand MW	MVAR	MVA	Minimum demand MW	MVAR	MVA	PF	LF
PL T1	13.8	13.90	1.90	14.03	1.80	-2.60	3.16	0.99	51%
PL 212	13.8	4.13	0.50	4.16	0.99	-1.35	1.67	0.99	46%
PL 213	13.8	6.85	1.91	7.11	1.36	-0.35	1.40	0.96	39%
PL 214	13.8	5.96	1.40	6.12	1.46	-0.13	1.47	0.97	44%
PL T2	13.8	14.00	1.90	14.13	0.20	-3.10	3.11	0.99	53%
PL 221	13.8	4.65	0.39	4.67	1.10	-1.03	1.51	1.00	46%
PL 222	13.8	3.50	0.47	3.53	0.80	-0.59	0.99	0.99	46%
PL 223	13.8	7.17	1.30	7.29	2.09	-0.65	2.19	0.98	53%
PL T3	13.8	14.06	2.19	14.23	3.47	-2.05	4.03	0.99	53%
PL 231	13.8	4.81	1.08	4.93	1.01	-1.03	1.44	0.98	62%
PL 232	13.8	4.86	0.59	4.90	1.13	-0.71	1.33	0.99	47%
PL 233	13.8	4.87	1.02	4.98	0.94	-0.51	1.07	0.98	46%
RH T1	13.8	19.00	3.20	19.27	4.80	-2.00	5.20	0.99	47%
RH 211	13.8	7.19	1.92	7.44	2.42	-0.27	2.44	0.97	54%
RH 212	13.8	4.58	1.31	4.76	0.67	0.09	0.68	0.96	41%
RH 213	13.8	2.45	-0.30	2.47	0.74	-0.90	1.17	0.99	54%
RH 214	13.8	5.43	0.87	5.50	0.90	-0.86	1.24	0.99	38%
RH T2	13.8	13.64	3.72	14.14	4.58	0.57	4.62	0.96	53%
RH 221	13.8	3.25	1.34	3.52	0.50	0.19	0.53	0.92	61%
RH 222	13.8	7.62	2.56	8.04	2.23	0.63	2.32	0.95	51%
RH 223	13.8	0.12	0.03	0.12	0.00	-0.04	0.04	0.97	
RH 224	13.8	3.34	0.71	3.41	0.59	-0.22	0.63	0.98	41%

APPENDIX E: MAXIMUM TRANSFER CAPABILITY THROUGH DISTRIBUTION FEEDER

From Bolstad (BD) Substation

				To Circuit (kVA)			
				Blue Ridge		Rebel Hill	Max. load transfer (kVA)
				BR	BR	RH	
				T1	T2	T1	
				BR 213	BR 221	RH 214	
From Circuit	BD	T1	BD 211				-
	BD	T1	BD 212		4,060		4,060
	BD	T1	BD 213			1,702	1,702
	BD	T2	BD 221				-
	BD	T2	BD 222				-
	BD	T2	BD 223	1,971			1,971

From Blue Ridge (BR) Substation

				To Circuit (kVA)								
				Bolstad		Harmony Branch	Power Plant		Rebel Hill			Max. load transfer (kVA)
				BD	BD	HB	PL	PL	RH	RH	RH	
				T1	T2	T2	T2	T3	T1	T1	T2	
				BD 212	BD 223	HB 222	PL 222	PL 233	RH 213	RH 214	RH 221	
From Circuit	BR	T1	BR 211					3,861				3,861
	BR	T1	BR 212			2,412		3,603				6,015
	BR	T1	BR 213		2,211				6,396	3,332	5,337	17,276
	BR	T2	BR 221	1,388								1,388
	BR	T2	BR 222				5,321					5,321

From Grindstone (GD) Substation

				To Circuit (kVA)						
				Hinkson Creek			Power Plant	Rebel Hill		Max. load transfer (kVA)
				HC	HC	HC	PL	RH	RH	
				T1	T3	T3	T3	T1	T1	
				HC 211	HC 231	HC 232	PL 231	RH 211	RH 212	
From Circuit	GD	T1	GD211	1,911						1,911
	GD	T1	GD212					1,368		1,368
	GD	T1	GD213							-
	GD	T2	GD221							-
	GD	T2	GD222					1,368		1,368
	GD	T2	GD223					1,368		1,368
	GD	T3	GD231							-
	GD	T3	GD232			4,387	2,997		2,997	10,381
	GD	T3	GD233		3,384					3,384

From Harmony Branch (HB) Substation

				To Circuit (kVA)											
				Blue Ridge	Harmony Branch		Hinkson Creek		Perche Creek				Power Plant		Max. load transfer (kVA)
				BR	HB	HB	HC	HC	PC	PC	PC	PC	PL	PL	
				T1	T2	T3	T2	T3	T1	T1	T1	T2	T1	T1	
				BR 212	HB 223	HB 231	HC 221	HC 233	PC 211	PC 212	PC 213	PC 222	PL 212	PL 213	
From Circuit	HB	T1	HB 211												-
From Circuit	HB	T1	HB 212												-
From Circuit	HB	T1	HB 213												-
From Circuit	HB	T2	HB 221									2,448			2,448
From Circuit	HB	T2	HB 222	2,234									4,685		6,919
From Circuit	HB	T2	HB 223			4,688	3,970	3,222		2,269	1,000			1,702	16,850
From Circuit	HB	T3	HB 231		3,734										3,734
From Circuit	HB	T3	HB 232						2,681	3,132	1,943				7,756
From Circuit	HB	T3	HB 233												-

From Hinkson Creek (HC) Substation

				To Circuit (kVA)									
				Grindstone			Harmony Branch	Perche Creek		Power Plant		Max. load transfer (kVA)
				GD	GD	GD	HB	PC	PC	PL	PL	
				T1	T3	T3	T2	T1	T2	T1	T1	
				GD211	GD232	GD233	HB 223	PC 213	PC 221	PL 213	PL 214	
From Circuit	HC	T1	HC 211	2,221								2,221
	HC	T1	HC 212									-
	HC	T1	HC 213					1,943				1,943
	HC	T2	HC 221				3,734	2,667				6,401
	HC	T2	HC 222									-
	HC	T2	HC 223					1,943	-			1,943
	HC	T3	HC 231			5,017						5,017
	HC	T3	HC 232		-							-
	HC	T3	HC 233				3,000			1,702	2,702	7,404

From Perche Creek (PC) Substation

				To Circuit (kVA)						
				Harmony Branch			Hinkson Creek			Max. load transfer (kVA)
				HB	HB	HB	HC	HC	HC	
				T2	T2	T3	T1	T2	T2	
				HB 221	HB 223	HB 232	HC 213	HC 221	HC 223	
From Circuit	PC	T1	PC 211			2,952				2,952
	PC	T1	PC 212		3,734	2,952				6,686
	PC	T1	PC 213		2,483	2,469	2,480	2,467	76	9,975
	PC	T2	PC 221						-	-
	PC	T2	PC 222	3,340						3,340
	PC	T2	PC 223							-

From Power Plant (PL) Substation

				To Circuit (kVA)									
				Blue Ridge			Grindstone	Harmony Branch		Hinkson Creek	Rebel Hill		Max. load transfer (kVA)
				BR	BR	BR	GD	HB	HB	HC	RH	RH	
				T1	T1	T2	T3	T2	T2	T3	T1	T2	
				BR 211	BR 212	BR 222	GD232	HB 222	HB 223	HC 233	RH 212	RH 222	
From Circuit	PL	T1	PL 212					2,412					2,412
	PL	T1	PL 213						3,734	2,078			5,812
	PL	T1	PL 214							3,222			3,222
	PL	T2	PL 221										-
	PL	T2	PL 222			2,818						764	3,583
	PL	T2	PL 223										-
	PL	T3	PL 231				2,688				4,075		6,763
	PL	T3	PL 232										-
	PL	T3	PL 233	2,873	2,234								5,107

From Rebel Hill (RH) Substation

From Circuit			To Circuit (kVA)								Max. load transfer (kVA)
			Bolstad	Blue Ridge	Grindstone				Power Plant		
			BD	BR	GD	GD	GD	GD	PL	PL	
			T1	T1	T1	T2	T2	T3	T2	T3	
			BD 213	BR 213	GD212	GD222	GD223	GD232	PL 222	PL 231	
RH	T1	RH 211			2,865	1,417	6,651				10,933
RH	T1	RH 212						2,688		3,907	6,595
RH	T1	RH 213		1,971							1,971
RH	T1	RH 214	2,360	1,052							3,412
RH	T2	RH 221		1,971							1,971
RH	T2	RH 222							5,321		5,321
RH	T2	RH 223									-
RH	T2	RH 224									-